

Pediatric Critical Care

Pediatric Critical Care

Principles of Pediatric Emergency Medicine in

- Emergency Departments
- Intermediate Care Units
- Intensive Care Units

Third Edition

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Pediatric Critical Care

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*Dedicated to
the souls of our dear colleagues we lost:
Doctor Mohamed Badawi
and
Doctor Haitham Hosni*

Preface to the Third Edition

In this new edition, many of the topics are updated to the latest available knowledge. The book becomes more illustrated with many new pictures and drawings. Two new sections (colored) on Pediatric ICU Equipment and Pediatric ICU Environment are added.

Mohammed El-Naggar

Preface to the Previous Edition

Pediatric critical care is the field of medicine dealing with acute life-threatening conditions in children. Emergency medical service in children (EMS-C) can be provided in emergency departments, intermediate care units or intensive care units depending on the severity of the condition, the duration of therapy and the necessity for sophisticated equipment. For instance, an episode of acute severe asthma can be successfully managed in emergency department, admitted and treated in intermediate care unit or transferred to an intensive care unit.

Unlike all other subspecialties in which the concern is directed to one system, critical care medicine is essentially dealing with all systems. The necessity for rapid recognition and urgent intervention, the multiplicity of maneuvers and equipment and the essential role of knowledge and skills are the main characteristics of this field.

It is important to emphasize that rapid, accurate and skilled clinical evaluation is by far the most important aspect in critical care medicine. The information gained through examination are quicker, more efficient and more reliable than investigations. Diagnostic procedures should be generally viewed as an additional step to clinical evaluation and not as a substitute to it. In addition, knowledge, understanding and ability to take proper decisions are the main differences between physicians and technicians.

In critical care medicine, and whatever the emergency, treatment should always start with the ABC (airway, breathing and circulation). As time is very precious, treatment should not be delayed until accurate history and detailed examination are made. Detailed evaluation should be only made after initial stabilization.

In this book, every sincere effort has been made to make it simple and practical, and I hope it can provide a quick guide to doctors dealing with critically ill children.

Mohammed El-Naggar

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Section 1

Emergency Resuscitation

- Cardiopulmonary Arrest
- Cardiopulmonary Resuscitation
- Neonatal Resuscitation

1 Chapter

Cardiopulmonary Arrest

Causes

Acute critical illness: Respiratory, cardiovascular, neurologic and metabolic emergencies
Stressful procedures: Suctioning, chest physiotherapy, intubation, lumbar puncture
Sudden withdrawal of support: Oxygen or mechanical ventilation

Diagnosis

Decompensation or pre-arrest: Slow respiration, bradycardia, decreased responsiveness
Cardiopulmonary arrest: No respiration, no heart beats, unresponsiveness

Cardiopulmonary arrest is the first and most urgent emergency in medicine. It is an emergency of only 5 minutes and unless adequate effective resuscitative measures are performed during this short period, irreversible damage of brain cells and even brain death will occur.

By definition, cardiopulmonary arrest is a sudden unexpected cessation of circulation and respiration in a patient who is unlikely to die and in whom the potentials for recovery are good. For such a patient, cardiopulmonary resuscitation is indicated. On the other hand, if the patient is suffering from a terminal illness as widespread malignancy or chronic advanced system failure, cessation of circulation and respiration do not necessitate any resuscitative measures.

CAUSES

Cardiopulmonary arrest can occur in any of the following situations:

- 1. Acute critical illnesses:** All patients with pediatric emergencies are susceptible because of the physiological instability. Patients with respiratory failure and circulatory failure are particularly more susceptible because of the resultant tissue hypoxia and acidosis. Primary cardiac disease is a rare cause of cardiac arrest in infants and children. This is different from the adult situation where cardiac arrest is often primary cardiac. The seven precipitating factors of cardiac arrest are (1) hypoxia, (2) shock, (3) acidosis, (4) electrolyte disturbance, (5) tension pneumothorax, (6) cardiac tamponade, and (7) hypothermia. These factors are called "the negative inotropes".
- 2. Stressful procedures:** In patients with acute critical illnesses, some procedures as suctioning, chest physiotherapy, endotracheal intubation and lumbar puncture may precipitate cardiopulmonary arrest. Oxygenation prior to any of these

techniques is important and careful observation during the technique is essential for early detection of signs of decompensation as bradycardia and slow respiration.

3. Sudden withdrawal of support: In patients with acute critical illness, sudden withdrawal of support (as oxygen therapy or mechanical ventilation) may precipitate arrest. As a rule, any form of support should be withdrawn gradually.

DIAGNOSIS

Clinical manifestations of cardiopulmonary arrest can be divided into 2 stages; early signs of decompensation (or pre-arrest) and the actual cardiopulmonary arrest (see below). Physicians and nurses dealing with pediatric emergencies should be fully oriented with the early signs of decompensation. Discontinuation of any stressful procedure and oxygen administration may rapidly reverse these manifestations. Proper treatment of the causative disease is equally important.

In patients with cardiopulmonary arrest, urgent cardiopulmonary resuscitation is indicated. It is important to note that cardiac arrest usually occurs first in case of respiratory failure (myocardial hypoxia) and circulatory failure (myocardial ischemia). On the other hand, respiratory arrest usually occurs first in case of central neurological failure (due to severe respiratory depression).

Criteria for diagnosis of cardiopulmonary arrest

Early signs of decompensation or pre-arrest

Respiratory: Cyanosis, slow respiration.

Cardiac: Bradycardia.

Circulatory: Weak pulse, poor peripheral perfusion.

CNS: Decreased responsiveness or restlessness.

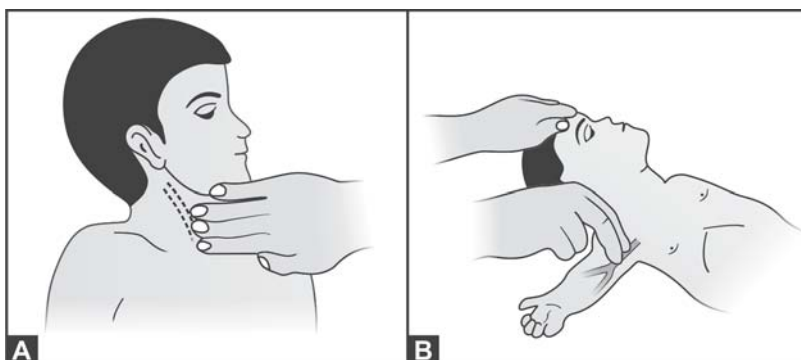
Cardiopulmonary arrest

Respiratory: No respiration (apnea or respiratory arrest).

Cardiac: No heart beats (cardiac arrest).

Circulatory: No pulse (pulseless) or peripheral perfusion.

CNS: No response to painful stimuli (unresponsiveness). Pupils are reactive.



Figs 1.1A and B: (A) Pulse check in children (Feeling the carotid pulse)
(B) Pulse check in infants (Feeling the brachial pulse)

2

Chapter

Cardiopulmonary Resuscitation

1. Basic life support (A+B+C)

It aims to restore spontaneous breathing and circulation

A: Airway control

Open the airway: Extend the head, pull the jaw forward and open the mouth.
Clear the airway: Remove foreign bodies and suction mouth and oropharynx.
Maintain patent airway: Insert oropharyngeal airway or endotracheal tube.

B: Breathing support (with artificial ventilation)

Mouth-to-mouth breathing (when equipments are not available).
Bag and mask ventilation (in hospital wards).
Bag and tube ventilation (in emergency departments or ICU).
(Ventilatory rate is 20 breaths/minute)

C: Circulation support (with cardiac compression)

Site of compression: Midsternum point.

Technique of compression

In newborns: Hand encircling technique.
In infants: Two fingers technique.
In young children: One hand technique.
In old children: Two hands technique.

Depth of compression: 2 cm (infant), 3 cm (young child), 4 cm (old child).

Frequency of compression: about 100/minute in all ages (8/5 seconds).

All together

Keep airway patent. Continue Ventilation and cardiac compression at a ratio of 1:5.

2. Advanced life support (D+E+F)

Indicated when basic life support was not successful (continued arrest).

Maintain A+B+C. Insert I.V. line and give Fluids (Ringer's lactate or normal saline), then

D: Drugs (I.V.)

Give sodium bicarbonate: 1 ml/kg of 8.4 solution or 2 ml/kg of 5% solution.

Give adrenaline: 0.1 ml/kg of diluted solution (1 ml + 9 ml saline).

E: ECG monitoring

It is important to detect various cardiac arrhythmias.

With asystole: Repeat adrenaline (10 times the first dose).

F: Fibrillation control

Indicated with ventricular fibrillation.

Defibrillate up to 3 times: 2 joules/kg, 4 joules/kg, 4 joules/kg.

3. Prolonged life support (G+H+I)

It is **the post-resuscitation management**. It has 3 objectives.

G: Gauge or evaluate

Recognition and treatment of the causative disease and precipitating factors.

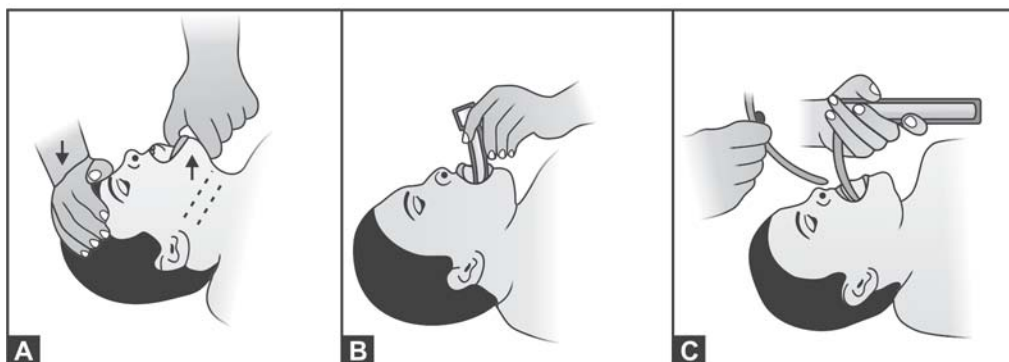
H: Humanize or brain recovery

A+B+C+ convulsion control + reduction of increased intracranial pressure.

I: Intensive care

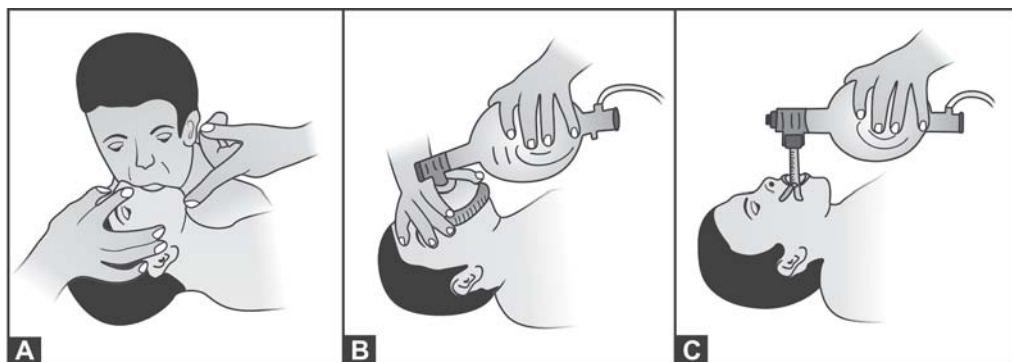
Multiple organ system support.

AIRWAY CONTROL



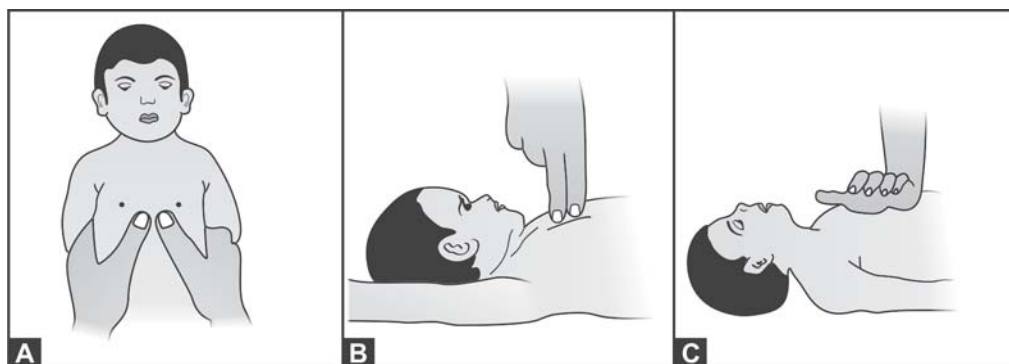
Figs 2.1A to C: (A) Airway opening (B) Oropharyngeal airway (C) Endotracheal tube

BREATHING SUPPORT



Figs 2.2A to C: (A) Mouth-to-mouth breathing (B) Bag and mask (C) Bag and tube

CARDIAC COMPRESSION



Figs 2.3A to C: (A) Hand-encircling technique (B) Two fingers technique (C) One hand technique

Cardiopulmonary resuscitation (CPR) is a real challenge against death. It aims to restore spontaneous respiration and circulation in a patient with cardiopulmonary arrest who is unlikely to die and in whom the potentials for recovery are good. The term **cardiopulmonary cerebral resuscitation (CPCR)** seems more appropriate because the real objective is **"to achieve survival without brain damage"**. As brain cells can tolerate total ischemia for only 5 minutes, effective resuscitative measures should be done during this short period to save the brain and to prevent brain damage. In many cases of successful recovery of respiration and circulation, the patient remains unconscious for several hours or days because of the temporary global brain ischemia that occurs during arrest and results in global ischemic encephalopathy. Moreover, in some children with successful resuscitation, brain death or cardiovascular death occurs hours or days later due to multiple organ system failure.

Cardiopulmonary resuscitation consists of 3 successive stages and each one consists of 3 steps (3 × 3).

- **Basic life support (BLS)** aims to provide emergency oxygen delivery to vital organs especially the brain and the heart.
- **Advanced life support (ALS)** aims to restore spontaneous circulation by supporting circulation and treatment of the life-threatening arrhythmias.
- **Prolonged life support (PLS)** aims to identify and treat the cause of arrest and to promote recovery of the brain, heart and other vital organs.

A. BASIC LIFE SUPPORT (BLS)

Basic life support consists of simple techniques that can maintain respiration and circulation to ensure emergency oxygen delivery to vital organs especially the brain and the heart. Basic life support can be effectively done *without equipment*. Ideally, ordinary people should receive training on basic life support to improve the outcome of children who have had cardiopulmonary arrest outside the hospital. More effective

resuscitative measures can be made in a hospital *with equipment*. All hospital personnel should receive training on basic life support.

Some important steps should precede the actual basic life support and can be summarized in the SAFE approach.

SAFE Approach

- S** : Shout for help (effective resuscitation needs more than one person).
A : Approach with care (the rescuer should not become a second victim).
F : Free from danger (the child should be quickly removed from continuing danger).
E : Evaluate ABC (Airway + Breathing + Circulation).

Actual basic life support is made in the following steps:

Airway Control

An obstructed airway may be the primary problem and correction of obstruction may result in recovery without further intervention. In the unconscious child, airway obstruction occurs by the tongue falling back to obstruct the pharynx. Pushing the jaw forward can relieve this obstruction. Airway control is made by the following steps:

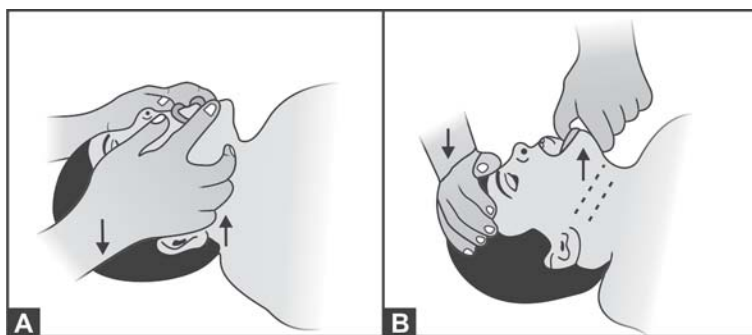
1. Airway opening: Triple airway maneuver is a simple technique to open the airways.

The head of the victim is held between the two hands of the rescuer with 2 or 3 fingers under the angle of the mandible bilaterally. Then, triple airway maneuver is made as follows:

- *Head tilt:* The head is extended backward by both hands.
- *Jaw thrust:* The jaw is pushed forward by the fingers under the angles of the mandible.
- *Mouth opening:* The mouth is opened by the thumb and index fingers.

Another alternative maneuver of airway opening can be made as follows:

- *Head tilt:* The head is extended backwards by one hand placed over the forehead.
- *Jaw thrust:* The jaw is grasped and pulled forward by the other hand with the thumb inside the mouth and other fingers under the chin.



Figs 2.4A and B: (A) Triple airway maneuver (B) Alternative maneuver

2. **Airway clearance:** Following airway opening, any obvious foreign body in the mouth should be cautiously removed. The finger sweep technique, recommended in adults, should be avoided in children because it may lead to damage of soft palate and may force foreign bodies further down causing more obstruction. In a hospital, suctioning of the mouth and oropharynx can be made.
3. **Oropharyngeal airway:** In a hospital, an oropharyngeal airway can be inserted in unconscious patient to provide a patent airway channel between the tongue and the posterior pharyngeal wall. In awake patient with an intact gag reflex it may not be tolerated and may provoke vomiting. There are different sizes suitable for infants, children and adults. The appropriate size suitable for any patient equals the distance between the center of the mouth and the angle of the jaw.
4. **Endotracheal intubation:** In an intensive care unit with experienced personnel, endotracheal intubation can be considered to ensure an adequate airway and to provide more effective manual ventilation with the bag and tube. The most suitable type of endotracheal tube is the plain plastic uncuffed tubes.
 - **Choice of the appropriate size:** There are different sizes of endotracheal tubes suitable for all ages. A useful simple guide is to use a tube with internal diameter equals the diameter of the child's little finger, or of such a size that will just fit into the child's nostril. Neonates usually require a tube size of 3 - 3.5 mm while prematures may need a size of 2.5 mm. In infants, young children and old children, sizes of 4.0, 4.5, 5.0, 5.5 mm can be used.
 - **Methods of insertion:** Endotracheal intubation can be made through the mouth (*oral route or orotracheal intubation*) or the nose (*nasal route or nasotracheal intubation*). Oral route is easier and more suitable in emergency situations. A *laryngoscope* is essential to visualize the larynx. There are two types of laryngoscope blades (curved blades and straight blades). The straight blade is preferred for children up to the age of 8 years. Size 1 blade is suitable for newborns and infants, size 2 for children up to the age of 10 years and size 3 is suitable for older children. *Preoxygenation* with 100% oxygen with the bag and mask is essential. Any intubation attempt should last no longer than 30 seconds. During intubation, the head should be kept in sniffing position to allow better visualization, and cricoid pressure may also be needed to prevent aspiration. A properly placed tube is confirmed by; (1) symmetric breath sounds, (2) symmetric

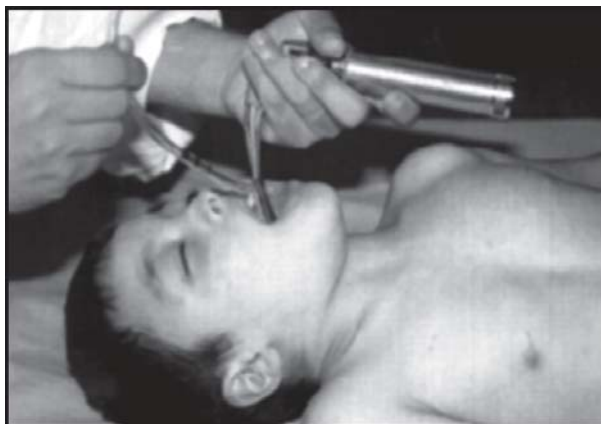


Fig. 2.5: Laryngoscope and endotracheal tube

chest movements, (3) absence of breath sounds over the stomach and (4) presence of condensation in the tube during expiration. A chest X-ray is also important to ensure the midtracheal tube position.

- **Length of fixation:** The appropriate length of fixation depends on the route and the age of the patient. The following formula can be used:
 - For oral tube: Length (cm) = (age/2) + 12.
 - For nasal tube: Length (cm) = (age/2) + 15.
- **Care of the tube:** Frequent **suctioning** of the tube (every 1-2 hours) is important to prevent tube obstruction. Preoxygenation with 100% oxygen with the bag and tube is essential. Suctioning can be made in 3 positions (head neutral, head to right and head to left). **Aerosol therapy** and **chest physiotherapy** before suctioning are important to liquefy and mobilize pulmonary secretions. It is important to remember that both chest physiotherapy and suctioning are stressful procedures; therefore, monitoring of the heart during these procedures is important.

Breathing Support

If the airway opening techniques do not result in resumption of breathing, artificial ventilation should be started immediately. This can be made by the following methods:

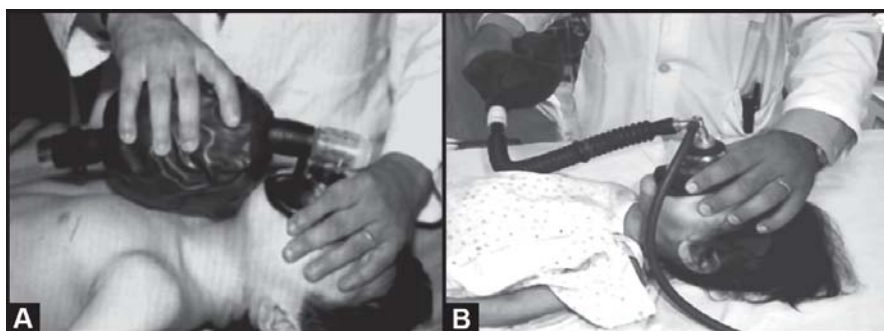
1. **Mouth-to-mouth ventilation:** While the head is kept extended by one hand placed over the forehead, the rescuer takes a breath and seals his mouth around the victim's mouth. The nose should be pinched closed by the index and thumb of the same hand over the forehead, while the other hand is placed under the chin to lift the jaw. In infants, the mouth of the rescuer can seal both the mouth and nose (Mouth-to-mouth and nose ventilation). Two slow breaths are then delivered while the rescuer is observing chest rise. If chest rise is adequate, rescue breathing may continue at a rate of 15-20/minute for the infant or child. The rescuer pauses to take a breath before delivering the next breath. If chest rise is insufficient, the airway is repositioned (head tilt, chin lift) and ventilation is reattempted. If ventilation is unsuccessful despite trials to open the airway, foreign body obstructing the airway should be suspected (see choking). It is important to remember that exhaled breaths contain 16% oxygen, which is sufficient to oxygenate the arrested patient.



Fig. 2.6: Mouth-to-mouth ventilation

2. **Mouth-to-mask ventilation:** In a hospital with available tight facemasks for assisted ventilation, mouth-to-mouth ventilation can be replaced by mouth-to-mask ventilation. The mouth is opened and the mask is tightly applied to cover the mouth and nose. Ventilation is made with the rescuer mouth sealing the opening of the mask. This method is more hygienic because it protects the rescuer from contact with patient secretions or vomitus.
3. **Bag and mask ventilation:** In a hospital, mouth-to-mouth or mouth-to-mask ventilation should be replaced as soon as possible with the bag and mask ventilation. The *self-inflating resuscitation bag (Ambu bag)* has 3 sizes; for newborns (250 ml), children (500 ml) and adults (1600 ml). The patient end of the bag connects to one-way valve and can fit to face masks. The opposite end has a connection to the oxygen supply and to a reservoir. The bag refills with room air (21% oxygen) unless an oxygen supply is connected (100% oxygen). An oxygen flow rate of 10 - 15 liters/minute is needed to maintain adequate oxygen in the reservoir. Effective ventilation with the bag and mask can be made with one or two operators.

It is important to mention that in children the mask is applied to the face with the right way up, while in infants it is applied upside down. Ventilation can be started with room air but it should be replaced with 100% oxygen as soon as possible. With each ventilation, observation of chest rise is important and repositioning of the head is made if chest rise is insufficient. The rate or *frequency of ventilation* is 15-20/minute for the infant or child. As an alternative, bag and mask ventilation can be made with *an anesthesia bag (Jackson Rees bag)* connected to oxygen supply. As this bag is not a self-inflating bag and its use needs experience, it is not generally recommended in resuscitation. However, the bag is commonly used in ICU because it has a T-piece, which allows spontaneous breathing.



Figs 2.7A and B: (A) Ambu bag (B) Anesthesia bag (connected to O₂)

4. **Bag and tube ventilation:** When bag and mask ventilation is not effective, an endotracheal tube should be immediately inserted and ventilation with 100% oxygen can be made with the bag attached to the endotracheal tube connector. Bag and tube ventilation has the following advantages:



Fig. 2.8: Bag and tube ventilation



Fig. 2.9: Endotracheal mechanical ventilation

1. More adequate airway.
 2. Better ventilation.
 3. Better suctioning.
 4. Endotracheal drug administration.
 5. Avoiding gastric distention, which commonly occurs with mouth-to-mouth or bag and mask ventilation.
5. **Mechanical ventilation:** When resuscitative efforts are prolonged or the primary illness necessitates prolonged respiratory support, bag and tube ventilation can be replaced with endo-tracheal mechanical ventilation. Ventilators are classified according to the method of termination of inspiration into 3 types (pressure cycled, time cycled and volume cycled). The most suitable in pediatrics is the time cycled-pressure limited type.

Types of assisted ventilation

Mouth ventilation

- Mouth-to-mouth ventilation (in children).
- Mouth-to-mouth and nose ventilation (in infants).
- Mouth-to-mask ventilation

Manual ventilation

- Bag and mask ventilation (without endotracheal intubation).
- Bag and tube ventilation (with endotracheal intubation).

Mechanical ventilation

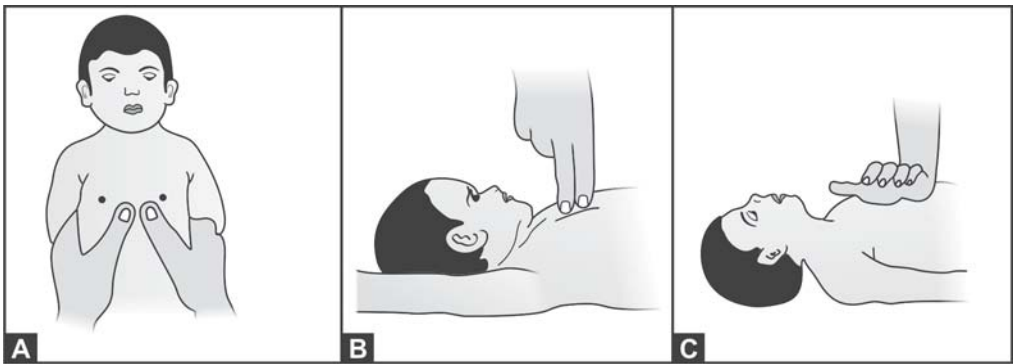
- Partial support (intermittent mandatory ventilation or IMV).
- Total support (controlled mechanical ventilation or CMV).

Circulation Support

Once the *initial five breaths* have been given by mouth-to-mouth or bag and mask ventilation, attention should be turned to circulation. Cardiac arrest is recognized by absent heart sounds or a central pulse for 5 seconds. In children, as in adults, the carotid artery in the neck can be palpated, but in infants the brachial artery (in the medial aspect of the upper arm) or the femoral artery (in the groin) should be felt.

In case of cardiac arrest, artificial circulation is made by the **external cardiac compression**. For the best results, the child should be placed on his back on a hard surface (**resuscitation board**). The site, technique, depth and frequency of cardiac compression vary according to the age of the victim:

- 1. Site of compression:** Simply and roughly, **the midsternum point** can be used in all ages. In infants, the best site is one finger breadth below the intermammary line (the line between the 2 nipples). In young children and old children, it is one finger breadth and two fingers breadth *above the xiphisternum* respectively.
- 2. Technique of compression:** In newborns and infants, the "**hand-encircling technique**" or the "**two finger technique**" can be used. In young children, the "**heel of one hand**" is used while in old children, the "**heel of both hands**" are used.



Figs 2.10A to C: (A) Hand encircling (B) Two fingers (C) One hand

- 3. Depth of compression:** The optimal depth of compression is 2 cm in infants, 3 cm in young children and 4 cm in old children. The sternum should be compressed in a perpendicular direction to force the blood out of the heart into the central circulation.
- 4. Frequency of compression:** In all ages, it is around 80 - 100 compression/ minute. In young infants, it should not be below 100/minute.

Cardiac compression at different ages

	Infant	Young child	Old child
Pulse check Site	Brachial/femoral One finger breadth Below nipple line	Carotid One finger breadth above xiphisternum	Carotid Two fingers breadth above xiphisternum
Technique	Two fingers	One hand	Two hands
Depth	2 cm	3 cm	4 cm
Frequency	100/minute	80-100/minute	80/minute

Putting ABC together

It should be remembered that throughout the basic life support, the *airway should be kept open* and both artificial ventilation and artificial circulation should continue simultaneously with a *ventilation/compression ratio* of 1:5 (one ventilation for each 5 cardiac compressions).

- (a) In case of one operator, each cycle consists of one ventilation followed by 5 cardiac compressions (*cyclic support*).
- (b) In case of two operators, one is responsible for ventilation and the other for cardiac compression (*simultaneous support*).

Evaluation of response

Repeated evaluation of cardiopulmonary function (ABC) should be made every few minutes as further intervention depends on the physiological condition of the patient. Patients can be physiologically classified into the following categories:

1. **Complete recovery:** Recovery of spontaneous respiration and circulation without evident system failure. Further management includes close observation and treatment of primary illness.
2. **Recovery with system failure:** Recovery of spontaneous respiration and circulation but with manifestations of one or more system failures (post-resuscitation system failure) as:
 - **Respiratory failure:** Rapid respiration, retractions and may be cyanosis. Management includes oxygen therapy and positive pressure support.
 - **Circulatory failure (shock):** Tachycardia, poor peripheral perfusion and hypotension. Management includes volume expanders (I.V. Ringer's lactate or saline) and inotropic drug support (dopamine I.V. infusion). The cause of shock is myocardial ischemia.
 - **Neurologic failure:** disturbed consciousness due to ischemic encephalopathy.
3. **Continued cardiopulmonary arrest:** Pre-arrest or decompensation (slow heart or bradycardia and slow respiration) is managed by continued assisted ventilation (with 100% oxygen) and atropine (I.V. or endotracheal). Continued arrest (absent heart sounds, apnea and unresponsiveness) requires advanced life support.

B. ADVANCED LIFE SUPPORT (ALS)

Advanced life support is indicated in *patients with continued cardiac arrest* after several minutes of basic life support. It aims to restore normal cardiac rhythm by circulation support and treatment of life-threatening arrhythmias.

The first step in management of cardiac arrest is to *continue basic life support* (ABC) because hypoxia is the most common cause of cardiac arrest. Endotracheal intubation should be considered as it ensures an adequate airway and allows more effective manual ventilation with the bag and tube. Moreover, several resuscitation drugs (adrenaline, atropine, lidocaine or naloxone) can be administered through the endotracheal route. Further management includes the following 3 steps:

Vascular access and fluid administration

1. **Intravenous route:** Immediate I.V. line should be established for fluid administration and drug therapy. Start infusion with volume expanders as Ringer's lactate or normal saline in an amount of 20 ml/kg over 10 minutes. This amount can be repeated once or even twice in case of advanced shock. It is important to remember that precious time should not be lost on trying to get an I.V. line because important drugs as adrenaline and atropine can be given via the endotracheal route.
2. **Intraosseous route:** When an I.V. line cannot be established, the intra-osseous route can be used as an alternative for drug therapy and fluid administration. A standard 16 or 18 gauge needle, spinal needle with stylet or bone marrow needle can be used. It is inserted into the anterior surface of the tibia 1-3 cm below the tibial tuberosity. The needle is directed perpendicular to the medial surface of the tibia and it should enter the marrow cavity, which is achieved if the needle stands upright without support. All fluids, drugs and even blood can be infused through this route.

ECG monitoring

ECG (electrocardiogram) monitoring of the heart is important for detection of various cardiac arrhythmias. A portable defibrillator screen or a heart rate and ECG monitor can be used. The most common arrhythmias are bradycardia (slow heart rate) and cardiac arrest (no palpable central pulse or audible heart beats). **Cardiac arrest** can be caused by one of three cardiac arrest rhythms; asystole, electromechanical dissociation or ventricular fibrillation.

1. **Asystole:** It is by far the most common arrest rhythm in children because the response of the young heart to severe hypoxia and acidosis is progressive bradycardia leading to asystole. The ECG appearance of ventricular asystole is an almost *straight line*. It is important to check that the appearance is not caused by a loose wire or disconnected electrodes.
2. **Electromechanical dissociation:** It is the absence of palpable pulse despite the presence of *recognizable complexes* on the ECG monitor. The most common cause in children is advanced shock, which makes the pulse very weak and difficult to feel. Other causes include electrolyte disturbance, tension pneumothorax and cardiac tamponade.
3. **Ventricular fibrillation:** This arrhythmia is uncommon in children but it may occur in those recovering from hypothermia and those with primary cardiac disease. It may follow ventricular tachycardia or occur suddenly following severe hypoxia, advanced shock or severe acid-base and electrolyte disturbance. The ECG shows complete disorganization with absent QRS complexes.

When immediate ECG is not available, the patient should be considered as having asystole (the most common) and should be managed as such.

Asystole

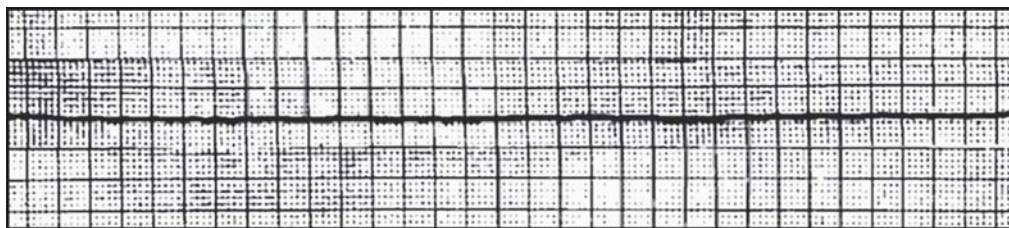


Fig. 2.11: Flat or straight line ECG

Ventricular tachycardia

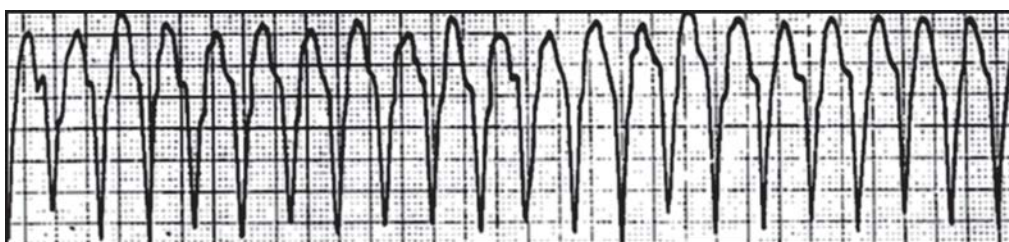


Fig. 2.12: Tachycardia with QRS complexes

Ventricular fibrillation

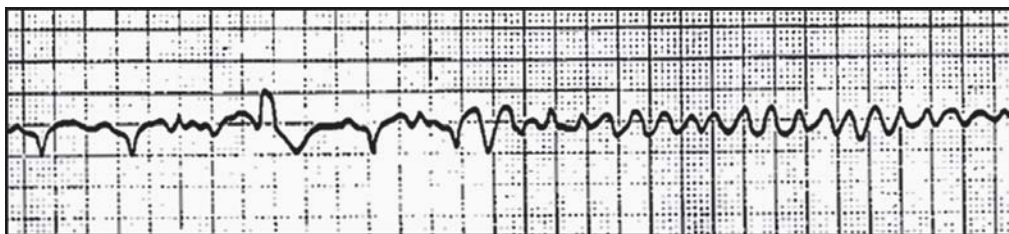


Fig. 2.13: Complete disorganization with absent QRS complexes

Treatment of life-threatening arrhythmias

Specific management of arrhythmias depends on the type of arrhythmia (see below). Drug therapy is usually given through the I.V. route. Intraosseous route is an emergency alternative. Endotracheal route can be used for adrenaline, atropine, lidocaine and naloxone. Sodium bicarbonate should not be given via the endotracheal route. **Treatment of the precipitating factors "negative inotropes"** especially hypoxia and shock is very important (see cardiopulmonary arrest).

Treatment of cardiac arrest

Asystole (flat ECG)

1. Continue ventilation with 100% oxygen (with bag and mask or bag and tube).
2. Continue cardiac compression.
3. Give sodium bicarbonate (IV only): 1 mEq/kg.
4. Give adrenaline (I.V. intraosseous or endotracheal):
 - First dose: 0.01 mg/kg of diluted solution (I.V. or intraosseous) or 0.01 mg/kg of undiluted solution (endotracheal).
 - Second dose: 0.1 mg/kg of undiluted solution (I.V. intraosseous or endotracheal). (Note that the second dose is 10 times the first dose)
 - Subsequent doses: 0.1 mg/kg or even 0.2 mg/kg of undiluted solution. (Repeat every 3 - 5 minutes if no response).

Electromechanical dissociation (pulseless electrical activity)

1. Identify and treat precipitating factors especially shock.
2. Give volume expanders as Ringers lactate or saline (20 ml/kg I.V. over 10 minutes).
3. Continue treatment as asystole (ventilation, cardiac compression, Na_2CO_3 and adrenaline).

Ventricular fibrillation (pulseless ventricular tachycardia)

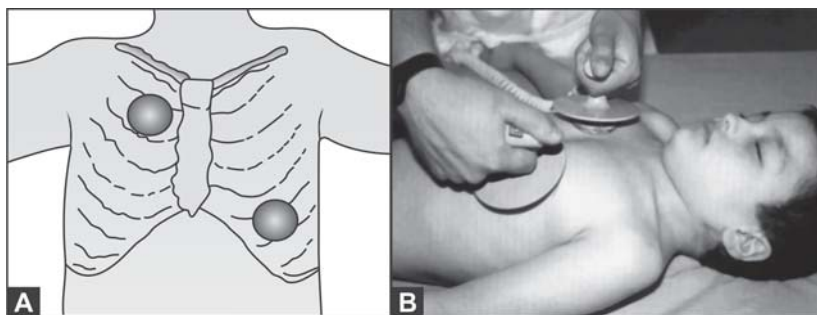
1. Continue treatment as asystole (ventilation, cardiac compression, Na_2CO_3 and adrenaline).
2. Defibrillate up to 3 times if needed: 2 Joules/kg, 4 Joules/kg, 4 Joules/kg.
3. Give lidocaine, I.V. intraosseous or endotracheal: 1 mg/kg.
4. Defibrillate again 30 seconds after medications: 4 Joules/kg, 4 joules/kg, 4 Joules/kg.
5. If no response after 9 shocks, use different paddle position or use another defibrillator.

C. PROLONGED LIFE SUPPORT (PLS)

Prolonged life support or post-resuscitation management starts once spontaneous circulation and a relatively normal rhythm has been established. Attention during this stage is directed to 3 objectives; (1) Recognition and treatment of the causative disease, (2) Brain recovery, (3) Intensive care for monitoring and multiple system support. The first step of management during this stage is the *immediate transfer to an intensive care unit* where facilities for investigations, monitoring and multiple system support are available. Diagnosis can be made according to the type and number of system failures. Examples of diagnosis are "*post-resuscitation global ischemic encephalopathy*" or "*post-resuscitation multiple organ system failure*".

Treatment of causative disease and precipitating factors

After restoration of a relatively normal cardiac rhythm, immediate investigations are necessary to identify and treat the causative disease. Similarly, correction of the precipitating factors (hypoxia, shock, acidosis, electrolyte disturbance, tension pneumothorax, cardiac tamponade and hypothermia) should be urgently done. It is important to remember that tension pneumothorax may be iatrogenic due to vigorous manual ventilation with the bag and mask or bag and tube, and hypothermia may also occur during cardiopulmonary resuscitation if measures to keep the body temperature are not considered.



Figs 2.14A and B: With electrical defibrillation, pediatric paddles (4.5 cm) should be used. One paddle is placed over the apex of the heart and the other paddle over the base (below the right clavicle just to right of the sternum). During defibrillation shock, no body should touch the patient to avoid electrical injury

Immediate investigations during the post-resuscitation stage

Arterial blood gases (ABG): To detect acidosis and hypoxemia.
 Serum electrolytes (Na, K, Ca): To detect electrolyte disturbance.
 Blood sugar level: To detect hypoglycemia or hyperglycemia.
 Renal function tests (blood urea and creatinine): To detect renal failure.
 Hematological tests (hemoglobin, hematocrit, platelets): To detect anemia or thrombocytopenia
 Chest X-ray: To detect tension pneumothorax or pulmonary infiltrate.

- Echocardiography may be needed to detect cardiac tamponade especially in case of shock not responding to volume expanders.

Brain recovery

In many cases of successful resuscitation from cardiac arrest, patients remain unconscious for several hours or days because of the temporary global brain ischemia that occurred during cardiac arrest. The resultant *global ischemic encephalopathy* leads to brain edema, which becomes clinically evident by unconsciousness, increased intracranial pressure and may be convulsions. The severity of these manifestations is directly related to the duration of cardiac arrest. Therefore, efforts to save the brain (**cerebral resuscitation**) should ideally begin at the moment of arrest with an effective basic life support to shorten the duration of brain ischemia. The aim of therapy during this stage is to preserve brain functions and to protect the brain from further (secondary injury), which may lead to brain death or permanent sequelae.

Cerebral resuscitation from global ischemic encephalopathy

Airway: Keep patent airway, put oropharyngeal airway, consider intubation.
 Breathing: Give oxygen (40-60%), consider mechanical ventilation.
 Circulation: Give I.V. fluids, treat shock or hypertension.
 Control of convulsion and prevention of further fits.
 Reduction of increased intracranial pressure.

Intensive care for multiple organ system support

Unfortunately, many children who have been resuscitated from cardiac arrest die hours or days later from multiple organ system failure (MOSF). In addition, to cellular damage that occurs during arrest, the process of cellular damage also continues after restoration of spontaneous circulation. This is called **ischemia-reperfusion injury** and it is caused by depletion of ATP, calcium influx into cells and production of free oxygen radicals. Global ischemic encephalopathy is an evident example of the ischemia-reperfusion injury. Similar injuries also occur in the heart, lungs, kidneys and GIT. Management during this stage aims to support different systems to achieve and maintain homeostasis in order to increase the chances for recovery.

Monitoring and multiple organ system support

Monitoring

Clinical monitoring: Heart rate and ECG, respiratory rate and respiratory waveform, blood pressure (by manual or automated methods), temperature (by thermometer or temperature probes), level of consciousness and pupillary changes, urine output, and arterial oxygen saturation (by pulse oximeter).

Laboratory monitoring: Arterial blood gases, serum electrolytes, blood urea and creatinine, blood sugar level, hemoglobin level.

Multiple organ system support

Respiratory support: Oxygen therapy, suctioning, positive pressure support.

Cardiovascular support: Oxygen therapy, I.V. fluids, inotropic support.

Neurologic support: A+B+C, convulsions control and reduction of ↑I. CP

Metabolic support: Correction of temperature, hydration and organ functions.

Hematologic support: Urgent transfusion and control of bleeding.

WHEN TO STOP RESUSCITATION

In case of continued cardiac and respiratory arrest, resuscitative efforts should continue as long as brain death does not occur. Repeated examination of eye reflexes (pupillary reaction to light and oculocephalic reflex) every 5 minutes is important. The decision to terminate efforts is made by the most experienced person of the team and is based on the presence of brain death despite 30 minutes of resuscitative measures. Exceptions to this rule include hypothermia (below 32°C) and overdoses of CNS depressant drugs. In these situations, prolonged efforts are necessary.

REQUIREMENTS FOR SUCCESSFUL RESUSCITATION

1. **Early diagnosis:** As cardiopulmonary arrest is an emergency of only 4-5 minutes, time factor is crucial. Close observation of critically sick patients is essential and medical personnel should be fully oriented with the early signs of decompensation (pre-arrest) and also the procedures that may precipitate cardiopulmonary arrest.
2. **Well organized and trained team:** Successful resuscitation requires more than one person. Ideally, 4 persons are needed:

- Operator 1: The most experienced person and the leader of the team. He takes care of respiration and gives orders to other persons. He also takes the decision when to stop resuscitation efforts.
- Operator 2: Responsible for external cardiac massage.
- Operator 3: Responsible for I.V. line and drug administration.
- Operator 4: Responsible for recording of the resuscitative measures and given drugs. A flow-sheet for resuscitative measures should be used.

Such a team should be assigned during every shift and before the event of arrest. Continuous training is of great value to improve the skills and to coordinate efforts. Practical training sessions with simulated arrest situations should be made.

3. **Availability of drugs and equipment:** During each hospital shift, the nurse should check for the availability of all emergency medications and equipment. It is also important to check that all equipments are functioning properly.

Resuscitation team

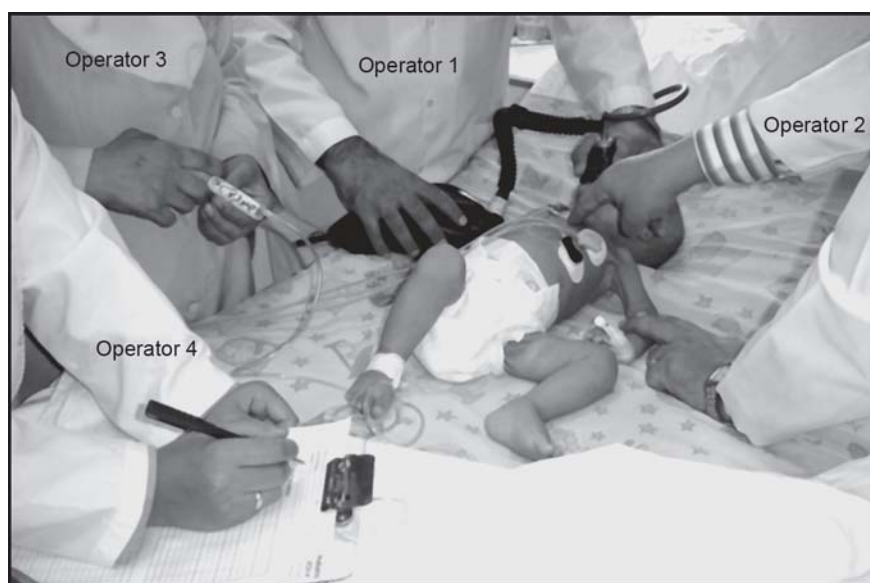


Fig. 2.15: The four operators of resuscitation team

Emergency resuscitation equipment and drugs

Airway equipment

- Portable electrical suction apparatus.
- Plastic suction catheters (sizes 5,6,7,8).
- Plastic oropharyngeal airways (sizes 0,1 2,3,4).
- Plastic endotracheal tubes (sizes 2.5, 3, 3.5, 4, 4.5, 5, 5.5).
- Endotracheal connectors.
- Laryngoscope handle with a functioning battery.
- Set of curved laryngoscope blades (Macintosh blades, sizes: 1, 2, 3).
- Set of straight laryngoscope blades (Miller blades, sizes: 1, 2, 3).
- Magill's forceps (to grasp the endotracheal tube in nasotracheal intubation).

Oxygen and ventilation equipment

- Oxygen source, oxygen flowmeter and oxygen humidifier.
- Oxygen masks for spontaneous breathing (venturi masks are preferable).
- Tight face masks for artificial ventilation (different sizes).
- Self-inflating bag (Ambu bag): 3 sizes; newborn, child, adult.
- Anesthesia bag (Jackson Rees bag): 2 sizes (500 ml and 1000 ml).
- Oxygen analyzer (to measure inspired oxygen concentration).
- Pulse oximeter (to measure arterial oxygen saturation).
- Chest tubes (for treatment of pneumothorax).

Circulation and vascular equipment

- Resuscitation board (30 x 50 cm).
- Defibrillator with monitor. ECG printer and pediatric size paddles.
- I.V. cannulas (sizes 16, 18, 20, 22) and adhesive tape.
- I.V. butterfly needles.
- Lumbar puncture needle or bone marrow needle (for intraosseous route).
- Disposable syringes (2 ml, 5 ml, 10 ml, 20 ml).
- I.V. sets and I.V. solutions (Ringer's lactate, normal saline).
- Devices for blood pressure measurement (manual or automated).
- Infusion pumps.

Other equipment

- Radiant warmer.
- Portable X-ray machine.
- Blood gas analyzer.

Emergency drugs

- Sodium bicarbonate (8.4% or 5% solution).
- Adrenaline ampoules (1 mg/ml).
- Atropine ampoules (1 mg/ml).
- Lidocaine vial (1 gm/50 ml).
- Dopamine ampoule (200 mg/5 ml).
- Dobutamine vial (250 mg).
- Diazepam ampoule (10 mg/2 ml).
- Calcium gluconate (1 gm/10 ml).

3 Chapter

Neonatal Resuscitation

Primary apnea (Apnea without bradycardia)

Diagnosis: cyanosis, apnea and heart rate above 80/minute

Management: **Simple measures** (suction, oxygen by mask, bag and mask ventilation)

Terminal apnea (Apnea with bradycardia)

Diagnosis: Pallor, apnea and bradycardia (heart rate below 80/minute)

Management: **vigorous measures** (oxygen by mask ventilation, endotracheal intubation and bag and tube ventilation)

Stillbirth (Apnea with cardiac arrest)

Diagnosis: Pallor, apnea and cardiac arrest (No heart beats)

Management: **Full cardiopulmonary resuscitation** (Bag and tube ventilation, cardiac compression and drugs).

With **poor response to resuscitative measures**, consider the following:

1. Faulty techniques.
2. Pulmonary causes (pneumothorax, diaphragmatic hernia, stiff lungs).
3. Cardiovascular causes (severe anemia, shock, congenital cyanotic heart disease).
4. CNS narcosis.

Immediately after delivery and within one minute of umbilical cord clamping, spontaneous respiration starts. Clamping of the cord results in hypoxemia, which is the main stimulus for respiration. Physical stimuli as cold air or tactile stimulation also stimulate respiration.

Simple assessment of the newborn immediately after birth can be made depending on 3 variables only; **color, respiratory effort and heart rate**. Healthy newborn is pink in color with good respiratory efforts and heart rate above 100/minute. These babies need only the routine care with no further treatment.

Newborns with apnea can be then broadly categorized into one of 3 groups:

1. **Primary apnea:** It is failure to initiate respiration mostly due to perinatal hypoxia or severe maternal sedation. The newborn is apneic and cyanosed but without bradycardia (heart rate above 80/minute). **Simple resuscitative measures** are indicated to avoid hypoxia and to improve the outcome. These measures include:
 - a. **Gentle suction:** Suctioning of the external nares and the mouth is useful to clear the airway and to stimulate respiration. Deep pharyngeal suctioning should be avoided as it may lead to bradycardia or laryngospasm.
 - b. **Oxygen:** Simple administration of 100% oxygen by a face mask is important to correct hypoxemia and to relieve cyanosis.

- c. **Bag and mask ventilation:** Failure of the above measures to initiate breathing and to relieve cyanosis is an indication for urgent bag and mask ventilation with 100% oxygen. Most babies of this category usually respond within 15 - 30 seconds and they start spontaneous breathing and become pink in color. Failure of response for one or two minutes to bag and mask ventilation at a rate of 40 - 60/minute is an indication to endotracheal intubation.
2. **Terminal apnea:** It occurs due to persistence of primary apnea and it leads to myocardial hypoxia and bradycardia. The newborn is apneic with bradycardia (below 80/minute) and may be pallor (cyanosis may be replaced by pallor due to circulatory insufficiency). These babies will not breathe without help and *vigorous resuscitative measures* are urgently indicated. These measures include:
- a. **Bag and mask ventilation:** Manual ventilation with bag and mask and 100% oxygen should be made at a rate of 40 - 60/minute. Successful ventilation is determined by good chest rise, heart rate above 100/minute, spontaneous breathing and pink color.
- b. **Endotracheal intubation:** Failure of response to bag and mask ventilation is an indication for urgent endotracheal intubation which allows better ventilation with the bag and tube. A normal newborn usually needs a tube size 3.0 but 2.5 and 3.5 tubes should be available. Intubation should be only made by experienced personnel.
- c. **Bag and tube ventilation:** Bag and tube ventilation with 100% oxygen should be made at a rate of 40 - 60/minute. Effective ventilation is determined by good chest rise, symmetric air entry and heart rate above 100/minute. Newborns with stiff lungs may need high pressure to inflate the lungs. Persistent bradycardia below 80 in spite of effective ventilation necessitates cardiac compression as well at a rate of 120/minute. Both ventilation and cardiac compression should continue at a ratio of 1:3.
3. **Fresh stillbirth:** It occurs with continued apnea and myocardial ischemia. The newborn is apneic, pale and pulseless (cardiac arrest). These babies need *urgent full cardiopulmonary resuscitation*. These resuscitative measures include:
- a. **Manual ventilation:** Initial bag and mask ventilation with 100% oxygen should be quickly replaced by endotracheal intubation and bag and tube ventilation. Ventilation should be made at a rate of 40 - 60/minute.
- b. **Cardiac compression:** As previously mentioned, cardiac compression should even start if the heart rate is below 80 in spite of effective ventilation. The encircling technique or the two fingers technique can be used at a rate of 120/minute. Both ventilation and cardiac compression should continue at a ratio of 1:3.
- c. **Drugs:** Failure of response to combined ventilation and cardiac compression for 30 seconds is an indication for drug therapy. Umbilical vein can be used for urgent drug administration. Adrenaline is given I.V. in a dose of 0.01 mg/kg and can be repeated after 5 minutes. If there is no response, the dose can be increased to 10 times the initial dose. Sodium bicarbonate can also be given in a dose of 1 - 2 mEq/kg, I.V. in case of prolonged resuscitation.

POOR RESPONSE TO RESUSCITATION

1. **Faulty techniques:** Poor response to ventilation may be due to unconnected oxygen source, loosely fitted face mask, insufficient pressure, poor positioning of the airway, wrong intubation or obstructed tube. All these possibilities should be excluded.
2. **Pulmonary causes:** Pneumothorax, diaphragmatic hernia and stiff lungs should be considered as possible causes of poor response.
 - a. **Pneumothorax:** It is usually iatrogenic due to vigorous manual ventilation with the bag and mask or more commonly with the bag and tube. Asymmetric air entry and mediastinal shift (apex beat) to the other side are the main findings. With clinical suspicion, transillumination of the chest with a cold light source is useful where a pneumothorax may show a hyper-illuminating area. A therapeutic test can be done by inserting a 21-gauge butterfly needle in the second intercostal space in the mid-clavicular line. The end of the butterfly tube should be in a small glass under saline. In case of pneumothorax, air bubbles will be seen in the saline and the baby will improve. A confirmatory chest X-ray can be then done and a chest tube is inserted.
 - b. **Diaphragmatic hernia:** Worsening of the condition with manual ventilation with the bag should suggest diaphragmatic hernia. The cause of deterioration is the distension of the herniated intestinal loops with air. Endotracheal intubation and manual ventilation with the bag and tube should be immediately made. Diagnosis can be confirmed by a chest X-ray, which shows multiple cysts of variable sizes (air-filled bowel) occupying the whole left hemithorax and pushing the mediastinum to the right side. Corrective surgery can be only made after stabilization of the condition.
 - c. **Stiff lungs:** When the lungs are stiff to ventilation, hyaline membrane disease, congenital pneumonia or meconium aspiration should be considered. In this case, manual ventilation should be made with a higher pressure sufficient to inflate the lungs.
3. **Cardiovascular causes:** Severe anemia, hypovolemia and congenital CHD.
 - a. **Severe anemia:** Persistent pallor in spite of effective ventilation and normal heart rate (or tachycardia) should suggest severe anemia due to severe hemolytic disease. An urgent non-cross-matched O negative blood should be used for exchange transfusion.
 - b. **Shock:** Persistent pallor and poor peripheral perfusion should suggest shock. Hypovolemic shock necessitates volume expansion (20 ml/kg of saline or Ringers lactate, I.V. over 10 minutes) followed by blood transfusion. Cardiogenic shock requires volume expansion followed by dopamine constant I.V. infusion.
 - c. **Congenital cyanotic heart disease:** Persistent cyanosis in spite of effective ventilation, normal heart rate should suggest the possibility of congenital CHD. Pulse oximeter can show the low arterial oxygen saturation (below 90%).

4. **CNS narcosis:** Persistent apnea in spite of effective manual ventilation (pink color and normal heart rate) should suggest CNS narcosis due to maternal narcotic analgesic drug administration. Naloxone (Narcan ampoule, 0.4 mg/ml) should be given I.V. in a dose of 0.01 mg/kg. The dose can be repeated every 3 minutes up to 3 times.



Section 2

Respiratory Emergencies

- Choking (FB Airway Obstruction)
- Stridor (Upper Airway Obstruction)
- Respiratory Distress (Lung Failure)
- Hypoventilation (Pump Failure)

Choking

4 (FB Airway Obstruction)

Chapter

Clinical diagnosis

In conscious patient: Sudden onset of coughing, stridor, choking or cyanosis.

In unconscious apneic patient: Unsuccessful assisted ventilation.

Relief of obstruction

In infants: Series of 5 back blows and 5 chest thrusts.

In children: Series of 5 abdominal thrusts in standing or lying down position.

Choking (or foreign body airway obstruction) is most common in late infancy and early childhood (6 months–4 years), the age at which children put objects in their mouths. The most common inhaled objects are foods (as peanuts) and small objects (buttons, beads, coins, safety pins).

CLINICAL DIAGNOSIS

A foreign body in the airway may cause partial or complete obstruction. **Partial obstruction** leads to sudden onset of coughing and stridor and cyanosis may occur in severe cases. **Complete obstruction**, on the other hand, causes sudden choking, cyanosis, loss of consciousness, apnea and cardiac arrest.

Clinical diagnosis of foreign body airway obstruction is not a clear-cut diagnosis. Positive history is helpful but the condition should be suspected with *sudden* onset of coughing, stridor and may be cyanosis.

Clinical situations suggesting foreign body airway obstruction

In conscious patient

Sudden onset of coughing, stridor, choking or cyanosis.

In unconscious apneic patient

When assisted ventilation (bag and mask) is not accompanied with chest rise and air entry. Repositioning of the head and re-ventilation are also not effective to cause chest rise.

- The most common causes of upper airway obstruction in children are infections of the larynx and trachea as laryngotracheobronchitis or acute epiglottitis. In these cases, the *onset is acute* (not sudden) and fever is commonly present. If infection is present, physical maneuvers to relieve obstruction are dangerous and contraindicated.

RELIEF OF OBSTRUCTION

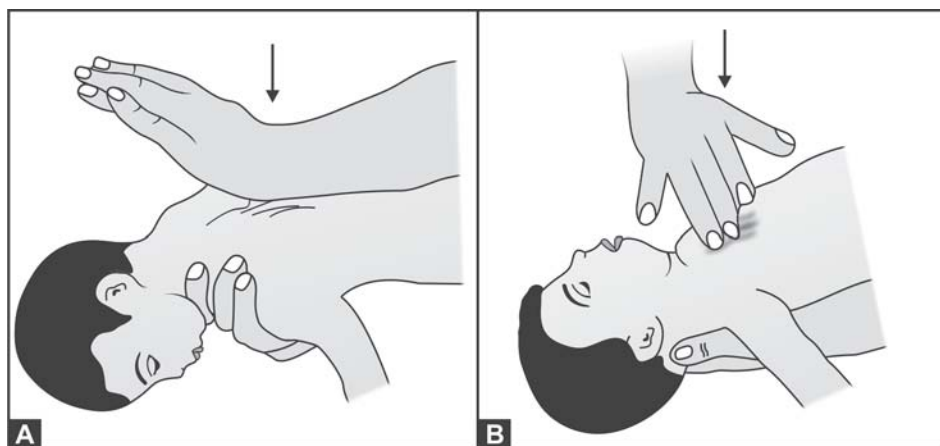
Physical maneuvers to clear the airway and to dislodge the foreign body are indicated when the clinical suspicion is strong. The maneuvers are different according to the age of the patient.

1. Maneuvers in infants

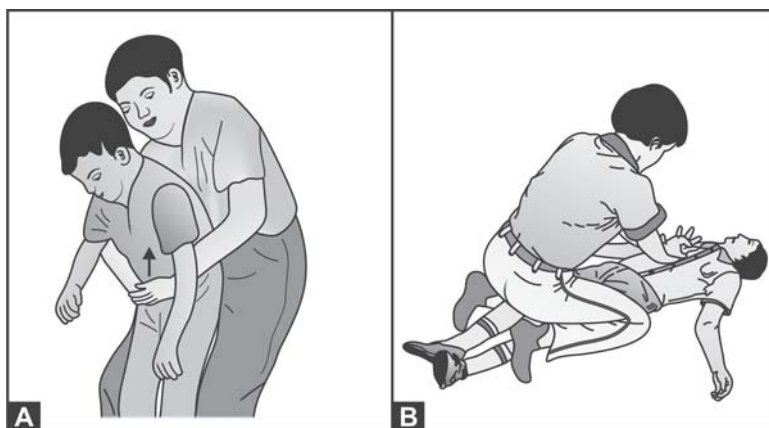
A combination of 5 *back blows* and 5 *chest thrusts* are indicated. The infant is placed along one of the rescuer's arm with the head lower than the trunk. The infant's head is supported with the rescuer's hand around the jaw and chest. *Five back blows* are rapidly delivered with the heel of the free hand between the infant's shoulder blades. The infant is then turned and placed on the rescuer's thigh with the head lower than the trunk. *Five chest thrusts* are then delivered in the same manner of cardiac compression (using the two-fingers technique) but at a slower rate. Back blows and chest thrusts induce an artificial cough, which increases pressure in the distally blocked respiratory passages and this may result in partial or complete dislodgement of the foreign body. Following these maneuvers, if a foreign body is visualized, it is then removed. If not visualized and spontaneous breathing is not restored, assisted ventilation is re-attempted and a series of back blows and chest thrusts is repeated.

2. Maneuvers in children

If the child is not cyanotic and has adequate air exchange, he should be allowed and encouraged to cough and breathe without interference. With signs of poor air exchange (inefficient cough, respiratory distress with retractions, stridor or cyanosis), maneuvers to dislodge the foreign body are indicated.



Figs 4.1A and B: (A) Back blows (B) Chest thrusts



Figs 4.2A and B: Abdominal thrust (A) Standing technique (B) Lying down technique

A series of 5 abdominal thrusts (subdiaphragmatic thrusts or Heimlich maneuver) are given while the child is standing, sitting or lying down on supine position. The series can be repeated.

- a. **In conscious child**, abdominal thrusts are given while the child is standing or sitting. The rescuer stands behind the child and passes his arms around the child's body and claps them in the midabdominal area below the xiphoid and exerts a rapid inward and upward thrust on the abdomen.
- b. **In conscious or unconscious child**, abdominal thrusts can be given while the child is lying down on supine position. The rescuer faces the patient and kneels astride his or her hips. The heel of one hand is placed on the abdomen below the xiphoid and above the umbilicus and the other hand is placed on the top of the first. Both hands are used to apply a sharp upward abdominal thrust.

5 Chapter

Stridor (Upper Airway Obstruction)

Clinical grading of stridor

Grade I (exertional stridor)

Stridor only appears during crying or exercise

Grade II (stridor at rest)

Stridor is present at rest and becomes worse with crying

Grade III (stridor with retractions)

Stridor at rest with suprasternal and supraclavicular retractions

Grade IV (stridor with cyanosis)

Stridor with retractions, cyanosis and disturbed consciousness

Causes of stridor

Infectious croup (most common)

Infectious laryngitis (most common)

Laryngotracheobronchitis (inspiratory and expiratory noise)

Spasmodic laryngitis (mainly occurs at night)

Acute epiglottitis (high fever and severe stridor)

Acute tracheitis

Other causes

Laryngeal foreign body (onset is sudden, no fever or any other illness)

Laryngospasm (may occur with hypocalcemic tetany)

Laryngeal edema (occurs with severe allergy or following extubation)

Laryngeal compression (with retropharyngeal hematoma or abscess)

Management of stridor

Home management (in mild cases)

Close observation (for severity of stridor)

Humidification (inhalation of hot steam)

Hospital management

Conservative treatment

Close observation (for severity of stridor)

Humidification (inhalation of hot steam)

Oxygen therapy (to avoid or correct hypoxemia)

Drug therapy (? Steroids, antibiotics)

Artificial airway

Endotracheal intubation—In severe cases not responding to above measures

Tracheostomy

Stridor is a continuous *inspiratory* harsh sound produced by *partial obstruction* in the region of larynx or trachea. Total obstruction leads to cyanosis and death. Stridor is commoner in infants and young children because of their smaller airway. Stridor should not be confused with other causes of noisy respiration especially wheezing.

Types of noisy respiration

Snoring	Inspiratory irregular sound produced by partial obstruction at the nasal, nasopharyngeal or oropharyngeal level.
Stridor	Inspiratory continuous harsh sound produced by partial obstruction at the level of the larynx or trachea.
Rattling	Inspiratory (\pm expiratory) irregular coarse sounds produced by partial obstruction of trachea and major bronchi by secretions. These sounds can be also felt (palpable rhonchi) and auscultated.
Wheezing	Expiratory continuous musical sound produced by partial obstruction at the level of the small bronchi and bronchioles. These sounds can be also auscultated.
Grunting	Early expiratory short sound produced by forced expiration against the closed Epiglottis. It is a sign of severe respiratory distress.

Stridor can be acute or chronic. With acute stridor, the onset is abrupt or acute and the duration of illness is short (less than a week). With chronic stridor the onset is rather gradual and the illness is extending over weeks or months. Acute stridor is much commoner and is life-threatening.

CLINICAL DIAGNOSIS

Initial evaluation of children with acute stridor should depend only on history and observation. History should include the age of the child, time and date of onset, duration, course, presence of fever or any preceding illness. Observation should include timing of stridor (exertional or continuous and inspiratory or biphasic), presence of respiratory distress (suprasternal and intercostal retractions), presence of cyanosis and the general appearance (normal, frightened, distressed or exhausted).

It is important to remember that maneuvers that disturb the child should be avoided as this may precipitate a sudden and severe deterioration of the general condition (see below). Chest auscultation can be only done if not causing disturbance of the child and should mainly concentrate on air entry (normal or decreased).

Rules for initial evaluation in acute stridor

- Do not disturb the child.
- Do not move the child from his preferred position.
- Do not separate the child from his mother's lap.
- Do not examine the pharynx or the larynx.
- Do not insert I.V. line or take blood sample.

Following initial evaluation, clinical diagnosis should include the degree of upper airway obstruction and the cause of stridor.

Degree of upper airway obstruction

Clinical assessment of the degree of upper airway obstruction is very important for the decision regarding the place and line of management.

Clinical grading of stridor

Grade I (Exertional stridor)

Stridor appears only during crying or with exercise.

Grade II (Continuous stridor or stridor at rest)

Stridor is present at rest and becomes worse with exertion.

Infants below the age of one year should be hospitalized.

Grade III (Stridor with retractions)

Stridor is continuous and accompanied with suprasternal and supraclavicular retractions.

The patient looks anxious, irritable and struggling for breathing.

Hospitalization is indicated for all cases.

Grade IV (Stridor with cyanosis)

In addition to continuous stridor and retractions, cyanosis and altered consciousness occur denoting severe respiratory failure.

Urgent hospitalization and endotracheal intubation are indicated.

Cause of stridor

Most cases of acute stridor are caused by common viral or bacterial infections of the larynx or trachea (infectious croup). The peak incidence of croup is in the second year of life and males are more frequently affected. Other causes of acute stridor especially laryngeal diphtheria and laryngeal foreign body should also be considered and excluded.

1. **Infectious croup:** Five clinical entities with increasing severity are recognized (3 viral and 2 bacterial). Viral infections are much commoner and are usually milder. Parainfluenza viruses are the principal agent but other viruses as influenza, adenovirus or respiratory syncytial virus may be responsible. With bacterial infections, fever is high and airway obstruction is severe. *Staphylococcus aureus* (acute bacterial tracheitis) and *hemophilus influenza* type b (acute epiglottitis) are the 2 main causative bacteria.
 - a. **Acute infectious laryngitis:** It is a common viral infection, which occurs mainly in children between 1 - 3 years. The illness starts with mild fever, rhinitis and croupy cough. Stridor appears 1 - 2 days later and is usually mild to moderate. Symptoms usually subside over few or several days.
 - b. **Spasmodic laryngitis:** It is a viral or probably allergic condition characterized by an attack of croupy cough and stridor that occurs principally at night. Stridor is usually moderate in severity and only lasts for several hours. The attack may be repeated at the nights of the second and third days but it is usually milder. Recurrences may occur (recurrent stridor).
 - c. **Laryngotracheobronchitis:** It is a common potentially serious viral infection, which mainly occurs in children below 3 years. The illness starts with mild to moderate fever, rhinitis and brassy cough. Stridor appears 1 - 2 days later and is

usually moderate to severe and both inspiratory and expiratory (characteristic). Chest examination reveals diminished air entry, prolonged expiration and expiratory rhonchi. Symptoms usually subside over 3 - 7 days but cough may remain longer.

- d. **Acute bacterial tracheitis:** This uncommon serious bacterial infection is mainly caused by staphylococcus aureus and principally occurs in children below 3 years. The illness starts with high fever and gradually progressing stridor. Airway obstruction becomes severe and the illness simulates acute epiglottitis but direct laryngoscopy reveals normal epiglottis. Polymorphonuclear leukocytosis is usually present.
- e. **Acute bacterial epiglottitis:** This uncommon very serious bacterial infection is mainly caused by hemophilus influenza type b and principally occurs in children above 3 years (3 - 7 years). The illness starts abruptly with high fever and rapidly progressing stridor. Airway obstruction becomes severe within hours. Cyanosis and death rapidly occur if urgent endotracheal intubation is delayed. Direct laryngoscopy reveals large edematous cherry red epiglottis with intensive inflammation around. Polymorphonuclear leukocytosis is usually present.

Clinical differentiation between the 5 types of infectious croup

Disease	Age	Fever	Stridor
Acute laryngitis	1 - 3 years	Mild	Mild
Spasmodic laryngitis	1 - 3 years	Absent	Moderate (at night)
Laryngotracheobronchitis	1 - 3 years	Mild to moderate	Moderate to severe
Acute tracheitis	Below 3 years	High	Severe (slow progression)
Acute epiglottitis	Above 3 years	High	Severe (rapid progression)

- Laryngotracheobronchitis is the only one with inspiratory and expiratory stridor.
2. **Other causes:** Other five conditions should also be considered in case of acute stridor.
 - a. **Laryngeal diphtheria (diphtheritic croup):** Although it is a rare cause, it should be considered especially in infants with severe stridor. As the illness usually occurs due to extension from a pharyngeal focus, throat examination reveals a *tonsillar membrane*. Fever is usually mild but toxemia is evident and cervical lymph nodes are enlarged. Direct laryngoscopy reveals edema, congestion and a pseudomembrane. Culture from the membrane is essential for diagnosis.
 - b. **Laryngeal foreign body:** Although it is not a common cause, it should be considered when the onset is sudden and not preceded by fever or any other illness. Direct laryngoscopy confirms the diagnosis.
 - c. **Laryngospasm:** It may occur in patients with *hypocalcemic tetany* but it is usually associated with corpopedal spasm. Diagnosis depends on the presence of hypocalcemia and a dramatic response to I.V. calcium gluconate. The attack is usually short but it may recur several times per day.
 - d. **Laryngeal edema:** It may occur with *severe allergy* as angioneurotic edema or serum sickness. It may also follow extubation of endotracheal tube especially with prolonged intubation (*post-extubation stridor*).

- e. **Laryngeal compression:** Acute laryngeal compression and stridor may occur with traumatic retropharyngeal *hematoma* or with retropharyngeal *abscess*. The possibility of retropharyngeal abscess should be considered in patients presenting with high fever, stridor and difficult swallowing. Characteristic features include drooling of secretions from the mouth due to difficult swallowing, hyperextension of the neck, and a bulge on the posterior pharyngeal wall. The diagnosis can be confirmed by a lateral X-ray of the nasopharynx or the neck, which reveals a retropharyngeal mass. CT scan is more sensitive.

Causes of high fever and stridor

Acute epiglottitis: Rapid progression, swollen epiglottis.

Acute tracheitis: Slow progression, normal epiglottis.

Retropharyngeal abscess: Slow progression, bulge on posterior pharyngeal wall.

MANAGEMENT

Management of infectious croup (more than 95% of cases of acute stridor) depends on the degree of airway obstruction, the age of the patient and the causative disease.

The essential initial step in management is the clinical decision of whether the case is for hospital or home management. Generally speaking, 95% of cases can be safely managed at home and only 5% of cases need hospitalization. Fewer than 5% of those admitted need endotracheal intubation and mechanical ventilation.

Home management

Most afebrile patients with mild infectious laryngitis, spasmodic laryngitis or mild laryngotracheobronchitis can be safely managed at home. Although there is no specific therapy, management may include the following:

1. **Warm moist environment:** This can be provided by taking the child into a bathroom and turning on the shower or hot taps. Inhalation of the hot steam will usually relieve minor obstruction within 30 - 60 minutes.
2. **Drug therapy:** No medication can favorably alter the course of illness. However, broad spectrum antibiotic (as ampicillin or amoxicillin) and oral steroids (as dexamethasone) may be used in borderline moderate cases to minimize the necessity for hospitalization. Expectorants may also be used in laryngotracheobronchitis.
3. **Observation:** Parents should be oriented to return to hospital if the condition worsens. Signs of progression include difficult feeding, respiratory distress or increasing stridor.

Hospital management

Hospital management is only needed in 5% of cases of infectious croup. Severe laryngotracheobronchitis, acute tracheitis and acute epiglottitis are the main entities requiring hospitalization.

Indications for hospitalization in acute stridor

Infants below 1 year with grade II stridor (stridor at rest).
 Infants or children with grade III stridor (stridor with retractions).
 Suspected bacterial disease (as those with high fever and severe obstruction).
 Grade IV stridor (stridor with cyanosis and/or altered consciousness) is an indication for immediate hospitalization and endotracheal intubation.

Hospital management includes the following aspects:

1. **Close observation:** Frequent monitoring of the heart rate, respiratory rate, degree of retraction, color and level of consciousness is very essential to assess the course of illness and to identify those in need of endotracheal intubation. Further useful information about the severity of illness can be provided by measurement of oxygen saturation with a pulse oximeter (see below). Arterial blood gases may also be needed with severe obstruction and suspected respiratory failure.

Grading of severity of airway obstruction by oxygen saturation

Grade I: Normal saturation (above 95%): Oxygen is not indicated.
 Grade II: Mild reduction (between 90- 95%): Oxygen may be used.
 Grade III: Moderate reduction (between 85 - 90%): Oxygen is indicated.
 Grade IV: Severe reduction (below 85%): Endotracheal intubation.

2. **Minimal disturbance:** Children with croup are often frightened and uncomfortable. Crying increases their oxygen demand and may increase laryngeal swelling. Therefore, nursing and medical procedures that disturb the child or increase anxiety should be minimized. The child is allowed to remain in his preferred position and the mother is allowed to stay with him for reassurance, at least until he sleeps.
3. **Humidification:** Warm moist atmosphere is generally useful. Inhalation of warm water vapor may be helpful in relieving the laryngeal obstruction although the mechanism of action is unknown. Ultrasonic nebulizer, if available, is frequently effective within 20 - 30 minutes.
4. **Drug therapy:** Although no medication can favorably alter the course of illness, corticosteroids, parenteral antibiotics and nebulized epinephrine may be used in certain conditions:
 - a. **Corticosteroids:** Although their use is controversial, they should be tried in severe cases to reduce laryngeal edema. Hydrocortisone (10 mg/kg/dose, I.V. every 6 hours) or dexamethasone (0.25 mg/kg/dose, I.V. or I.M. every 12 hours) can be used for 2 - 3 days. Inhaled corticosteroids (beclomethazone, budesonide or fluticasone) every 4 - 6 hours may also be useful and can be used as an alternative in older children.
 - b. **Antibiotics:** Parenteral antibiotic therapy is important when bacterial origin is suspected especially in those with high fever. A second-generation cephalosporin as cefuroxime (100 mg/kg/day, I.V. in 2 - 3 divided doses) can be used for

5 - 7 days. Ampicillin or newer broad-spectrum penicillins as sultamicillin or co-amoxiclav (50 - 100 mg/kg/day, I.V. in 3 divided doses) are an alternative.

- c. **Nebulized adrenaline:** This treatment should be only used in children with severe obstruction to "Buy time" until urgent transfer to intensive care unit is made and an experienced team for endotracheal intubation is available. Nebulized adrenaline (1 ml of 1:1000 solution) given with oxygen through a face mask will produce a transient improvement for 30 - 60 minutes. Marked tachycardia is usually produced but other side effects are uncommon. The mechanism of action of adrenaline is unknown, but it may involve topical vasoconstriction and temporary decrease in swelling.
 - d. **Sedatives and bronchodilators are contraindicated:** Sedatives will impair the level of consciousness and decrease the work of breathing which is an important compensatory mechanism. Bronchodilators increase oxygen requirements.
5. **Oxygen therapy:** It is important to relieve hypoxemia, it has 2 main disadvantages. First, it delays the appearance of cyanosis, which is an important indication for endotracheal intubation or tracheostomy. Second, it is commonly rejected by the child and makes him more upset. However, oxygen can be used if the patient tolerates it and if observation is too close. It can be given by a head box or an oxygen mask. Monitoring of oxygen saturation by pulse oximeter is important for proper assessment of the degree of hypoxemia.
6. **Feeding:** Maintenance I.V. fluid therapy is usually needed during the first 24 hours to ensure adequate hydration. Careful oral intake is usually initiated from the second day.
7. **Artificial airway:** Up to 5% of children admitted to hospital with croup require endotracheal intubation. The decision to intubate is a clinical one and based on the presence of increasing distress, appearance of cyanosis, altered consciousness, extreme restlessness or exhaustion. The mean duration of intubation in croup is 5 days. If a difficulty in intubation is expected, an ENT surgeon capable of performing tracheostomy should be present.

Rules of endotracheal intubation in infectious croup

1. Ideally, should be done under general anesthesia with experienced team.
2. May be done in ICU under sedation with experienced personnel.
3. Tube size smaller than usual is required (due to laryngeal narrowing).
4. Nasotracheal intubation is preferable for better fixation of the tube.
5. CPAP with pressure 4- 5 mm H₂O and oxygen 40% can be used.
6. Mechanical ventilation can be used in cases complicated with pulmonary edema.
7. Equipment of reintubation should be available to be used if self-extubation occurs.
8. Equipment of tracheostomy should be available to be used if intubation is difficult.
9. Extubation is recommended when an air leak around the tube can be heard with coughing or with manual ventilation and when the amount of endotracheal secretions has diminished.



Fig. 5.1: Humidification by ultrasonic nebulizer

The patient is receiving humidified oxygen through a head box. The head of the child is not visible because of the dense fog produced by the nebulizer.

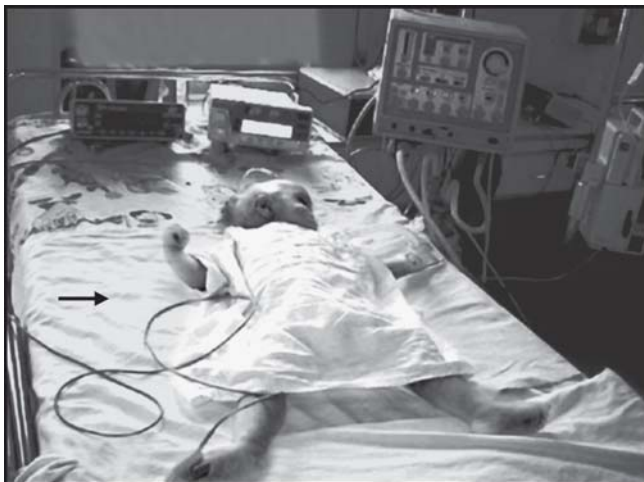


Fig. 5.2: Endotracheal intubation in severe obstruction

The patient is intubated and receiving constant pressure support (CPAP). Note the probe of the pulse oximeter connected to the right big toe.

6 Chapter

Respiratory Distress (Lung Failure)

Clinical grading of respiratory distress

Grade I (Mild distress = increased rate of breathing)

Rapid respiration (tachypnea) and working alae nasi

Grade II (Moderate distress = increased depth of breathing)

Tachypnea with intercostal and subcostal retractions

Grade III (Severe distress = increased pressure of oxygenation)

Expiratory grunting (early expiratory sound to increase oxygenation pressure)

Grade IV (Advanced distress = failure of compensatory mechanisms)

Cyanosis and altered consciousness

Causes of respiratory distress

Pulmonary causes

Pneumonias

Acute bronchiolitis

Acute asthmatic episode

Other cause: Pneumothorax, pleural effusion, massive lung collapse, pulmonary edema, obstructive emphysema, acute respiratory distress syndrome (ARDS)

Extrapulmonary causes

Acute congestive heart failure: Tachycardia, tachypnea and tender liver

Acute metabolic acidosis: Deep rapid respiration (acidotic breathing)

Acute severe anemia: Intense pallor (Hemolytic or following bleeding)

Management of respiratory distress

Respiratory Monitoring

Clinical monitoring: Heart rate, respiratory rate and degree of respiratory distress

Arterial oxygen saturation (by pulse oximeter)

Arterial blood gases (to assess oxygenation, ventilation and acid-base status)

Respiratory support

Oxygen therapy (to correct hypoxemia. It is the most important line of therapy)

Aerosol therapy (important to liquefy airway secretions)

Chest physiotherapy and suctioning (important to improve ventilation)

Positive pressure support (with failure of the above measures)

Manual ventilatory support (with self-inflation bag = Ambu bag)

Mechanical ventilatory support (with mechanical ventilator)

Specific treatment

According to the causative disease

Respiratory distress is the most common emergency in infancy and childhood. Pneumonia, acute bronchiolitis and acute asthmatic attack are by far the most common causes. Extrapulmonary causes especially acute congestive heart failure and acute metabolic acidosis should be routinely excluded.

DIAGNOSIS

Diagnosis of respiratory distress should include the degree and the cause of distress. It is important to emphasize that diagnosis should not delay therapy and oxygen should be immediately given to any distressed patient.

Degree of Distress

Clinical assessment of the degree of distress is important for determination of the severity and course of illness and for choice of the appropriate line of respiratory support.

Rapid respiration is the first compensatory mechanism of the body to improve oxygenation and ventilation. **Retractions** are more marked with obstructive airway disease. With severe obstruction, suprasternal retractions also occur. Retractions are caused by forceful contractions of intercostal muscles and diaphragm to improve ventilation through increasing the tidal volume. **Grunting** is mainly evident in neonates and infants with severe alveolar disease and it may be absent in obstructive airway disease. It is the last compensatory mechanism of the body to improve oxygenation. It aims to increase intra-alveolar pressure (physiological PEEP). **Cyanosis** appears after failure of all compensatory mechanisms and it indicates a frank respiratory failure with PaO_2 below 35 mm Hg. **Altered consciousness** occurs due to severe hypoxemia and/or marked CO_2 retention (CO_2 narcosis occurs with PaCO_2 above 60 mm Hg).

Respiratory distress (lung failure) should not be confused with respiratory weakness (pump failure).

Types of respiratory failure

	Lung failure	Pump failure
Other names	Type I respiratory failure Peripheral respiratory failure	Type II respiratory failure Central respiratory failure
Basic defect	Poor arterial oxygenation	Alveolar hypoventilation
Causes	Causes of respiratory distress <ul style="list-style-type: none"> • Pulmonary causes • Extrapulmonary causes 	Respiratory pump failure <ul style="list-style-type: none"> • Respiratory depression (deep coma) • Respiratory paralysis • Respiratory fatigue (severe lung failure)
Clinically	Respiratory distress Chest signs	Shallow breathing, cyanosis Coma or paralysis
Blood gases	Arterial hypoxemia (low PaO_2) ± hypoventilation (high PaCO_2) Acute respiratory acidosis	Hypoventilation (high PaCO_2) ± arterial hypoxemia (low PaO_2) Acute respiratory acidosis
Therapy	Oxygen therapy ± assisted ventilation	Assisted ventilation ± oxygen therapy

Cause of distress

In spite of the long list of conditions presenting with respiratory distress, it is usually not difficult to distinguish between the different causes based on the history, examination and simple investigations.

Diagnostic approach of respiratory distress

History

History suggesting pneumonia (Fever, preceding upper respiratory infection).
History of previous similar attacks: Bronchial asthma, diabetic ketoacidosis.
History of aspiration during feeding or aspiration of foreign body.
History of accidental poisoning: Organic phosphorus or salicylates.
History suggesting renal disease: Acute renal failure.

Examination

Intense pallor: Severe anemia.
Deep rapid respiration with altered consciousness: severe metabolic acidosis.
Tachycardia, tachypnea and tender liver: Acute congestive heart failure.
Chest signs
Unilateral diminished air entry: Effusion, pneumothorax, emphysema, collapse.
Fine consonating crepitations: Bronchopneumonia, bronchiolitis, ARDS.
Course crepitations (drowned chest): Aspiration, pulmonary edema, organic phosphorus.
Expiratory wheezing: Bronchiolitis, asthma, foreign body, heart failure.
Lobar bronchial breathing: Lobar pneumonia, lobar collapse.
Systemic examination
Hypertension, arrhythmias or cardiac murmurs: Acute congestive heart failure.
Bulbar paralysis or limb paralysis: Respiratory paralysis.
Severe diarrhoea and dehydration: Metabolic acidosis, ARDS.

Investigations

Chest x-ray (In ALL cases): To distinguish between different pulmonary causes.
Blood gases (In ALL cases): To detect metabolic acidosis and respiratory failure.
Sepsis screen (CBC, ESR, CRP): With suspected pneumonia.
Renal function (Blood urea, creatinine): With suspected acute renal failure.
Blood sugar level: With suspected diabetic ketoacidosis.
Echocardiography: With suspected cardiac disease.

PULMONARY CAUSES

1. **Pneumonia:** It is the commonest cause of respiratory distress in infants and young children. Fever and preceding rhinitis are important associated findings. Diagnosis should include the pathological type (lobar, bronchopneumonia, interstitial pneumonia), the cause (bacterial, viral or other agents) and the associated complications.
2. **Acute bronchiolitis:** It is a common cause of respiratory distress and expiratory wheezing in infants. Clinical differentiation from other causes of acute wheezing is important.
3. **Acute asthmatic attack:** Bronchial asthma is the commonest cause of recurrent respiratory distress and wheezing in children. Clinical differentiation from other

causes of recurrent wheezing is important. Diagnosis should include the severity of the acute attack, cause of the acute attack as well as the type of asthma (see acute asthma and drug therapy).

4. **Aspiration syndromes:** The possibility of aspiration should always be considered when the onset is sudden and not preceded by any illness. *Foreign body inhalation* is an important cause of respiratory distress and wheezing not responding to bronchodilators. *Aspiration of foods or medicines* is an important cause of sudden distress, which may lead to aspiration pneumonia or even to cardiopulmonary arrest. Chest examination usually reveals coarse bubbling crepitations. *Recurrent aspiration* should suggest gastroesophageal reflux, tracheoesophageal fistula or cricopharyngeal incoordination. *Near-drowning* (water aspiration) is occasionally the cause. Aspiration should not be confused with other causes of coarse bubbling crepitations especially pulmonary edema and organic phosphorus poisoning.
5. **Pulmonary edema:** It is a serious condition characterized by transudation of fluids from pulmonary capillaries into the interstitial spaces and alveoli. The illness results from both *cardiac* (increased capillary pressure) and *noncardiac* (increased capillary permeability or increased negative interstitial pressure) causes. Clinically, respiratory distress and coarse bubbling crepitations are the main findings. Chest X-ray reveals a hazy to opaque infiltrate, which may be more on one side. Clinical evaluation should also be directed to identify the causative disease.

Causes of pulmonary edema

Increased pulmonary capillary pressure (Cardiogenic pulmonary edema)

Severe acute congestive heart failure (especially severe myocarditis).
Postoperative period of open-heart surgery.

Increased pulmonary capillary permeability

Severe pneumonia (fulminant bacterial or viral interstitial pneumonia).
Aspiration pneumonia and near-drowning.
Inhalation pneumonia (toxic gases as ammonia, NO₂ or high oxygen concentration).
Adult respiratory distress syndrome (ARDS).
Severe septic shock with endotoxemia (diffuse capillary leak syndrome).
Anaphylaxis with release of vasoactive substances as histamine or leukotrienes.
Renal diseases (glomerulonephritis, acute and chronic renal failure).
Iatrogenic fluid overload (from too rapid or too large intravenous fluids).

Increased negative interstitial pressure

Severe upper airway obstruction (as epiglottitis) causing negative interstitial pressure.
Rapid expansion of collapsed lung with pneumothorax (re-expansion pulmonary edema).

Other causes

Neurogenic pulmonary edema: With increased intracranial pressure or severe head injury.
High altitude pulmonary edema.

6. **Adult respiratory distress syndrome (ARDS):** It is a catastrophic lung disease characterized by a diffuse alveolar-capillary membrane injury, which results in impairment of oxygenation and development of interstitial and alveolar pulmonary edema. Shock (especially septic shock) is the most important cause

and hence the disease is also known as "*shock lung*". Other less frequent causes include DIC, drug overdosage, toxic gas inhalation and aspiration. The mechanism of capillary injury is through the release of potent mediators from endotoxins, several cells (including neutrophils, macrophages, eosinophils) and platelets. These mediators include oxygen free radicals, proteolytic enzymes, arachidonic acid metabolites, platelet activating factor and fibrin degradation products. The condition should be suspected in any critically sick patient who develops respiratory distress. Severe gastroenteritis and dehydration is a good example. Respiratory distress usually appears within 2 days of the lung injury and it is usually severe, accompanied with cyanosis and resistant to simple oxygen therapy. Chest auscultation is initially free but fine bilateral crepitations soon appear. Chest X-ray reveals fine reticular or reticulonodular infiltrate. With frank pulmonary edema, hazy to opaque infiltrate appears. Prognosis is bad and prolonged mechanical ventilation is always necessary and can be life-saving.

7. **Pleural effusion:** Bacterial pneumonias are by far the most common cause of pleural effusion and empyema in infants and young children. The illness should be suspected in any case of respiratory distress with markedly diminished air entry over one side. Stony dullness over the involved side and mediastinal shift to the other side are usually evident. Urgent chest X-ray reveals a dense opacity occupying one hemithorax with mediastinal shift to the other side.
8. **Pneumothorax:** Beyond the neonatal period, isolated pneumothorax (without fluid) is uncommon and is mainly caused by mechanical ventilation, chest surgery, chest trauma, severe bronchitis, severe pertussis and severe interstitial pneumonia. In addition to respiratory distress, markedly diminished air entry and hyperresonance over the involved side are evident with mediastinal shift to the other side. Urgent chest X-ray reveals hypertransradiant hemithorax with absent bronchovascular markings and mediastinal shift to the other side.
9. **Localized obstructive emphysema:** Obstructive emphysema of a whole lung results from incomplete obstruction of the right or left main stem bronchus mostly by a foreign body of viscid secretions. Clinically, respiratory distress and diminished air entry over the affected side are the main findings. Chest X-ray reveals hypertransradiant hemithorax with preserved bronchovascular markings and some mediastinal shift to the other side.
10. **Massive lung collapse:** Massive collapse of one lung results from complete obstruction of its main stem bronchus mostly by foreign body. It may also occur following chest surgery or in intubated patients if the tube is advanced in one main stem bronchus (usually the right), which leads to complete obstruction of airflow and collapse of the other lung (usually the left). Clinically, respiratory distress, diminished air entry and bronchial breathing over the affected side are the main findings. Chest X-ray reveals opaque hemithorax with mediastinal shift to the same side of the lesion.

11. **Organic phosphorus poisoning:** This serious insecticide poisoning should be considered in patients presenting with respiratory distress, profuse chest secretions and may be bronchospasm and wheezing. Associated lacrimation, salivation, disturbed consciousness and miosis (or pinpoint pupils) make the possibility great. The condition should be differentiated from other causes of respiratory distress with coarse bubbling crepitations especially aspiration and pulmonary edema (see also wheezing).
12. **Bronchopulmonary dysplasia:** It is an important cause of chronic cough, chronic or persistent respiratory distress and chronic wheezing. The illness mostly occurs in neonates and young infants who were subjected to prolonged mechanical ventilation (see neonatal respiratory distress).
13. **Bronchiolitis obliterans:** It is a serious complication of several infectious agents especially adenovirus, mycoplasma and pertussis. It is characterized by chronic cough, chronic or persistent respiratory distress and chronic wheezing. The condition should be suspected in patients with acute bronchiolitis when the course is extending over weeks without an apparent improvement. Chest X-ray reveals a pulmonary infiltrate (miliary, reticulonodular or parahilar peribronchial).
14. **Respiratory paralysis:** With *acute paralysis* of respiratory muscles, the respiration becomes shallow and rapid. Clinically, bulbar paralysis and limb paralysis are the main presentation. The condition results in alveolar hypoventilation with CO₂ retention (pump failure or central respiratory failure). Guillain-Barre syndrome is the most common cause. Diphtheria, botulism and poliomyelitis are other causes. In severe cases, prolonged mechanical ventilation is lifesaving. *Gradual chronic* respiratory paralysis occurs with Werdnig-Hoffmann disease, muscular dystrophies and myasthenia gravis.

Causes of persistent or chronic respiratory distress

Slowly resolving pneumonia (inadequate therapy, immunodeficiency, obstructive bronchial lesions).
 Adult respiratory distress syndrome (ARDS).
 Persistent emphysema or collapse.
 Bronchopulmonary dysplasia.
 Bronchiolitis obliterans.
 Respiratory paralysis.

EXTRAPULMONARY CAUSES

1. **Acute congestive heart failure:** Clinical diagnosis depends on the presence of the cardinal triad of 3 T (tachycardia, tachypnea and enlarged tender liver). In severe cases, pulmonary edema and/or cardiogenic shock occur (see congestive heart failure).
2. **Acute metabolic acidosis:** The possibility of metabolic acidosis should always be in mind in every case of respiratory distress. Clinical diagnosis depends on the presence of deep rapid respiration (Kussmaul or acidotic breathing). In severe cases, disturbed

consciousness becomes evident. Clinical suspicion should be confirmed by blood gas analysis where all parameters are low (pH, bicarbonate and PaCO₂). The *severity of acidosis* can be determined by the degree of lowering of pH and bicarbonate level.

Normal blood gases		Grades of metabolic acidosis		
pH	7.35 - 7.4	pH	Bicarbonate	
Bicarbonate	20 - 24 mEq/litre	Mild	Below 7.3	Below 16 mEq/litre
PaCO ₂	35 - 40 mm Hg	Moderate	Below 7.2	Below 13 mEq/litre
PaO ₂	90 - 100 mm Hg	Severe	Below 7.1	Below 10 mEq/litre
For assessment of acid-base status, venous samples are satisfactory		Profound	Below 7.0	Below 7 mEq/litre

The cause of acidosis can be identified by both clinical and laboratory evaluation. Gastroenteritis and dehydration, acute renal failure and diabetic ketoacidosis are the most common. In critically sick patients, shock, hypoxia and sepsis should be also considered. In patients with respiratory failure, picture of "mixed metabolic and respiratory acidosis" occurs where the pH is markedly decreased while bicarbonate and PaCO₂ are near normal values. Acute metabolic acidosis may also occur on top of chronic acidosis. The main causes of chronic acidosis are aminoacidopathies, disorders of carbohydrate metabolism (glycogenosis type I and disorders of intermediary carbohydrate metabolism), renal tubular acidosis and chronic renal failure metabolic acidosis should not be confused with other acid-base disturbances whether isolated or mixed.

Disorders of acid-base balance				
	Metabolic acidosis	Respiratory acidosis	Metabolic alkalosis	Respiratory alkalosis
pH	Low	Low	High	High
Bicarbonate	Low	High	High	Low
PaCO ₂	Low	High	High	Low

3. **Acute severe anemia:** Massive hemorrhage or severe hemolytic crisis is commonly associated with rapid respiration due to severe hypoxia. Intense pallor and altered consciousness (hypoxic anemic encephalopathy) are the main findings. With acute hemolytic anemia, dark urine and mild jaundice may also be present.

MANAGEMENT

Monitoring, respiratory support and specific treatment of the cause form the foundation of management of infants and children with respiratory distress.

Respiratory monitoring

Clinical monitoring, arterial oxygen saturation and arterial blood gases are the three main parameters. As treatment of sick children is carried out by different teams throughout the 24 hours (*Multiple caregivers system*), proper recording in "flow sheet" is the only way of effective communication.

1. **Clinical monitoring:** Repeated measurement of heart rate and respiratory rate and degree of respiratory distress every 1-3 hours is important. Continuous display of heart rate and respiratory rate on a "monitor" is preferable because cardiopulmonary arrest may occur unexpectedly.
2. **Arterial oxygen saturation (SaO₂):** Repeated or continuous measurement of arterial oxygen saturation by pulse oximeter is a simple, noninvasive and reliable bedside method for assessment of the degree of hypoxemia. It is also relatively inexpensive, safe, accurate and portable. It measures the pulse rate and the per cent saturation of hemoglobin with oxygen. The probe of oximeter has a minilight source on one side and a photodetector on the other side. When it is applied to a vascular bed, the light traverses a pulsating capillary bed and the heart rate photodetector measures the spectro-photometric absorption of reduced hemoglobin (Hb) and oxyhemoglobin (HbO₂). The measured oxygen saturation is the *percentage of oxyhemoglobin to total hemoglobin*. Inaccurate results may be obtained in shock (poor perfusion), optical interference and methemoglobinemia.

Arterial oxygen saturation (SaO₂) by pulse oximeter

Site of probe placement

Newborns: The whole foot.

Infants: The palm of the hand or big toe.

Children and adults: Any finger.

In shocked patients: The ear lobule, nose or penis.

Significance of measured oxygen saturation

Above 95%: Normal.

90-95%: Mild hypoxemia.

85- 90%: Moderate hypoxemia.

Below 85%: Severe hypoxemia.

Results can be interpreted as:

- Without oxygen therapy (room air)
- With oxygen therapy

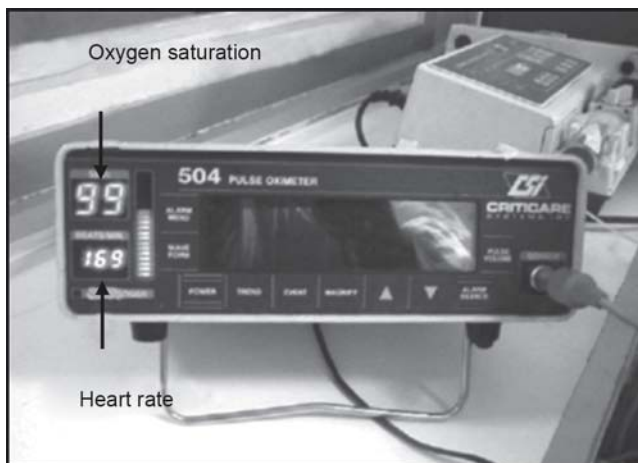


Fig. 6.1: Pulse oximeter

3. Arterial blood gases (ABG): Repeated measurement of arterial blood gases (by blood gas analyzer) is the most sensitive and reliable method for assessment of the state of oxygenation, ventilation and acid-base balance. Although arterial sampling (from radial or dorsalis pedis artery) is the ideal, arterialized (or capillary) sampling is also satisfactory. It is important to remember that pH is the most important single *parameter* and other parameters (PaO_2 , PaCO_2 and bicarbonate) should be interpreted on the light of measured pH. A normal or near normal pH is very unlikely to be associated with any significant serious acute illness.



Fig. 6.2: Blood gas analyzer

Value of arterial blood gases (ABG) in respiratory distress

State of oxygenation (by PaO_2)

Normal value of PaO_2 is 90-100 mm Hg.
 Value below 70 mm Hg means hypoxemia.
 Value below 50 mm Hg indicates hypoxemic respiratory failure.
 Value below 35 mm Hg is associated with central cyanosis.
 Value above 100 mm Hg occurs with oxygen therapy or poor sampling (air in sample).

State of ventilation (by PaCO_2)

Normal value of PaCO_2 is 35-40 mm Hg.
 Value between 45-50 mm Hg indicates mild hypoventilation.
 Value between 50-60 mm Hg indicates moderate hypoventilation.
 Value above 60 mm Hg indicates severe hypoventilation.
 Value below 30 mm Hg indicates hyperventilation.

State of acid-bas balance (by pH, bicarbonate and PaCO_2)

Normal pH (7.35-7.4) means no significant serious acute illness.
 Low pH with low bicarbonate indicates metabolic acidosis.
 Low pH with high PaCO_2 indicates respiratory acidosis.
 Very low pH with near normal bicarbonate and PaCO_2 indicates mixed metabolic and respiratory acidosis (metabolic due to hypoxemia and respiratory due to hypoventilation).
 High pH with high bicarbonate indicates metabolic alkalosis due to excess bicarbonate therapy. High pH with low PaCO_2 indicates respiratory alkalosis due to hyperventilation.

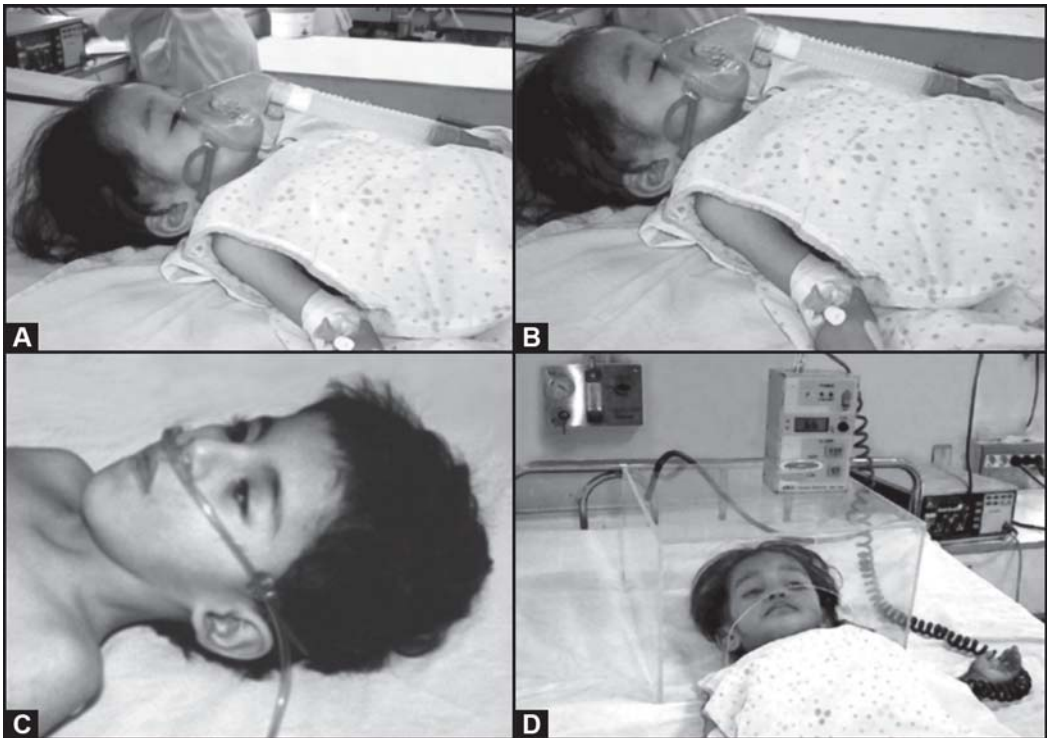
- **Arterial blood gas analysis** should be also interpreted in relation to the clinical condition (degree of distress) and the given respiratory support (oxygen, CPAP or assisted ventilation). For instance, normal ventilation can be caused by marked compensatory effort by the patient (retractions) and normal oxygenation can be produced by oxygen therapy.
- **Arterial blood gases** can be repeated as frequent as necessary. Any change in respiratory support (oxygen or ventilation) is expected to cause a change in arterial blood gases within 5 - 10 minutes.

Respiratory support

The principal goal of respiratory support is to ensure an adequate respiratory gas exchange (oxygenation and CO_2 elimination). Respiratory support in its simplest form consists of oxygen therapy and clearing of respiratory passages from secretions through chest physiotherapy and suctioning. A more advanced step is the positive pressure support of ventilation by continuous positive airway pressure (CPAP) or assisted ventilation. In the extreme, the lungs are completely bypassed and oxygenation is made outside the body (extracorporeal membrane oxygenation or ECMO).

1. Oxygen therapy: Oxygen administration is the most simple and most essential element in respiratory support. It is indicated in all cases of respiratory distress. Cyanosis is an urgent indication to oxygen therapy with 100% concentration. Oxygen corrects hypoxemia and increases pressure of arterial oxygen (PaO_2) through increasing fraction of inspired oxygen (FIO_2) and pressure of alveolar oxygen (PAO_2).

- **Method of administration:** Head box (in infants) and oxygen masks (in children) are the most commonly used methods. Nasal catheter (or nasal prongs) may also be used if tolerated by the patient. Oxygen should not be given in the dry form and humidification should be made by using a "humidifier".



Figs 6.3A to D: (A) Simple oxygen mask (B) Venturi oxygen mask (C) Nasal catheter (D) Head box

- **Dosage or concentration:** Oxygen should be given in a concentration that relieves cyanosis and corrects hypoxemia. Practically, start therapy with 40% oxygen then the concentration can be increased or decreased (10% by time) according to the response. In case of cyanosis, start with 100% and decrease gradually (over few hours) to 40 - 60%. Measurement of oxygen concentration can be made by an "oxygen analyzer". Once oxygen is indicated, it should be given continuously and with-drawn gradually. Duration of therapy depends on the causative disease. It may be only for few hours (as in acute allergic asthma) or may extend for several days (as in pneumonia and bronchiolitis).



Fig. 6.4: Oxygen analyzer (It measures O_2 concentration inside the head box)

- **Evaluation of response:** Good response to oxygen is associated with (1) absent cyanosis and some decrease in the severity of respiratory distress, (2) arterial oxygen saturation (SaO_2) above 95% or at least above 90%. This can be checked by repeated measurement of oxygen saturation by a pulse oximeter, (3) arterial oxygen pressure (PaO_2) above 90 mm Hg. Persistent low saturation (below 85%) and severe hypoxemia (PaO_2 below 60 mm Hg) in spite of 60 -70% oxygen is an indication for positive pressure support with continuous positive airway pressure or assisted ventilation.
 - **Assessment of severity of lung pathology:** In patients receiving oxygen, the degree of ventilation-perfusion mismatch can be measured by one of several indices known as "oxygen derived pulmonary indices". The most simple index is the *arterial/inspired oxygen ratio* or (PaO_2/FIO_2). Normal value is 400- 450 (90/0.2). Value below 200 indicates a severe pathology and severe ventilation-perfusion mismatch. Another important value of these indices is to allow comparison of different blood gas results in the same patient at different inspired oxygen concentrations (for details of oxygen therapy, see therapeutic interventions).
- 2. Aerosol therapy:** In contrast to humidification, which means "presence of water in a gaseous state", aerosol means "presence of suspended small particles of a substance (water, saline or drug) in a delivered gases". Aerosol therapy is used for:
- Liquefaction of thick secretions:** The most commonly used liquefying agent is normal saline and it is usually given through ultrasonic nebulization. This form of therapy is usually made before chest physiotherapy and suctioning.
 - Inhalation of medications:** Bronchodilators are the mainly used inhaled medications. Inhalation can be made by one of 2 methods depending on the age; (1) pressurized atomizers (or inhalers) suitable for old children, and (2) Nebulizers suitable for infants and young children (for details of aerosol therapy, see therapeutic interventions).

3. Chest physiotherapy and suctioning:

These simple measures are very effective in improving alveolar ventilation through mobilization and removal of pulmonary secretions. As these maneuvers are stressful to critically sick patients, hyperoxygenation with 100% oxygen is essential before and after these techniques.

a. Chest physiotherapy can be done by several techniques including postural drainage, chest percussion or clapping, vibration and deep breathing exercises.

b. Suctioning of tracheobronchial secretions is indicated in patients who are unable to cough effectively or unable to mobilize the accumulated secretions. It is also necessary in patients with an artificial airway (endotracheal tube or tracheostomy tube) to keep the airway patent and to prevent tube obstruction (for details of chest physiotherapy and suctioning, see therapeutic interventions).

4. Positive pressure support: This form of respiratory support is indicated when other simple measures of support are not effective to improve oxygenation and/or ventilation.



Fig. 6.5: Oropharyngeal suctioning

Indications of positive pressure support

Persistent arterial hypoxemia

Arterial oxygen saturation below 85% in spite of 70% oxygen therapy.

PaO₂ below 60 mm Hg in spite of 70% oxygen therapy.

Cyanosis in spite of 100% oxygen therapy.

Alveolar hypoventilation

Altered consciousness or PaCO₂ above 60 mm Hg (due to severe ventilation-perfusion mismatch or respiratory muscle fatigue).

Positive pressure support can be manual or mechanical, and mechanical support can be constant, intermittent or combined. Each mode of support has its own indications, methods of administration and limitations.

Types and modes of positive pressure support

Manual ventilatory support

Bag and mask ventilation.

Bag and tube ventilation.

Mechanical ventilatory support

Continuous positive airway pressure or CPAP (constant pressure support).

Intermittent mandatory ventilation or IMV (partial intermittent pressure support).

Controlled mechanical ventilation or CMV (total intermittent pressure support).

Mixed support (IMV or CMV plus positive end expiratory pressure or PEEP).

- a. **Manual ventilatory support:** Human hand is the best ventilator, but because of human fatigue, mechanical ventilators were invented. Manual ventilatory support is indicated when facilities for mechanical ventilation are not available or when all beds in ICU are occupied. Intermittent ventilation with the bag and mask for few minutes every 15 - 20 minutes is the simplest form. Bag and tube ventilation is more effective and can be used when experienced personnel in intubation and tube care are available.
- b. **Mechanical ventilatory support:** All ventilators are capable of providing the different modes of positive pressure support in addition to humidified oxygen at different concentrations from 21% to 100%. In newborns, infants and young children, time-cycled pressure-limited ventilators are the most suitable.
- (i) **Continuous positive airway pressure (CPAP):** It is a form of constant pressure support in which the airway pressure is constantly positive throughout respiration (in normal respiration, the airway pressure is negative during inspiration and positive during expiration). It is indicated in case of persistent hypoxemia in spite of the 70% oxygen therapy. Severe pneumonia, pulmonary edema and adult respiratory distress syndrome (ARDS) are the main indications. CPAP can be provided through a nasal catheter (nasal CPAP), nasopharyngeal tube (nasopharyngeal CPAP) or endotracheal tube (endotracheal CPAP). A constant pressure of 4 - 6 cm H₂O is usually used in addition to 40-70% oxygen. CPAP improves oxygenation through increasing the functional residual capacity (FRC) and distention of the atelectatic and poorly ventilated alveoli. These effects will improve ventilation-perfusion matching and decrease the work of breathing. High pressures above 7 - 8 cm H₂O are serious and may lead to pneumothorax or impairment of venous return.
 - (ii) **Intermittent mandatory ventilation (IMV):** In this form of partial pressure support, a number of mandated breaths per minute, usually less than the respiratory rate of the patient, are given to spontaneously breathing patient (i.e. the ventilatory rate given by the ventilator is less than the patient spontaneous rate). In other words, the ventilatory process is partially made by the mandated breaths and partially by the patient's spontaneous efforts. This form of support is indicated in case of CPAP failure or with hypoventilation (PaCO₂ above 60 mm Hg). This form of support is only given through the endotracheal tube, and it is commonly combined with positive end expiratory pressure (PEEP). Some ventilators are capable of delivering the mandated breaths only during inspiration (synchronized IMV or SIMV). Although the idea seems attractive, SIMV has no practical advantage over the ordinary IMV.
 - (iii) **Controlled mechanical ventilation (CMV):** In this form of total support, the ventilator is controlling the whole process of ventilation without depending on the patient's spontaneous efforts. The number of mandated breaths per minute are equal or even exceeding the respiratory rate of

the patient, and the patient's spontaneous efforts are either absent or ineffective. It is used in 2 conditions (1) Lung failure when IMV fails to correct hypoxemia due to either incoordinated mandated and spontaneous breaths (ventilator fighting by the patient) or markedly increased work of breathing. Transient paralysis of respiratory muscles with pancuronium may be needed to allow proper coordination between the patient and the ventilator, (2) Pump failure due to CNS respiratory depression (apnea) or neuromuscular respiratory paralysis.

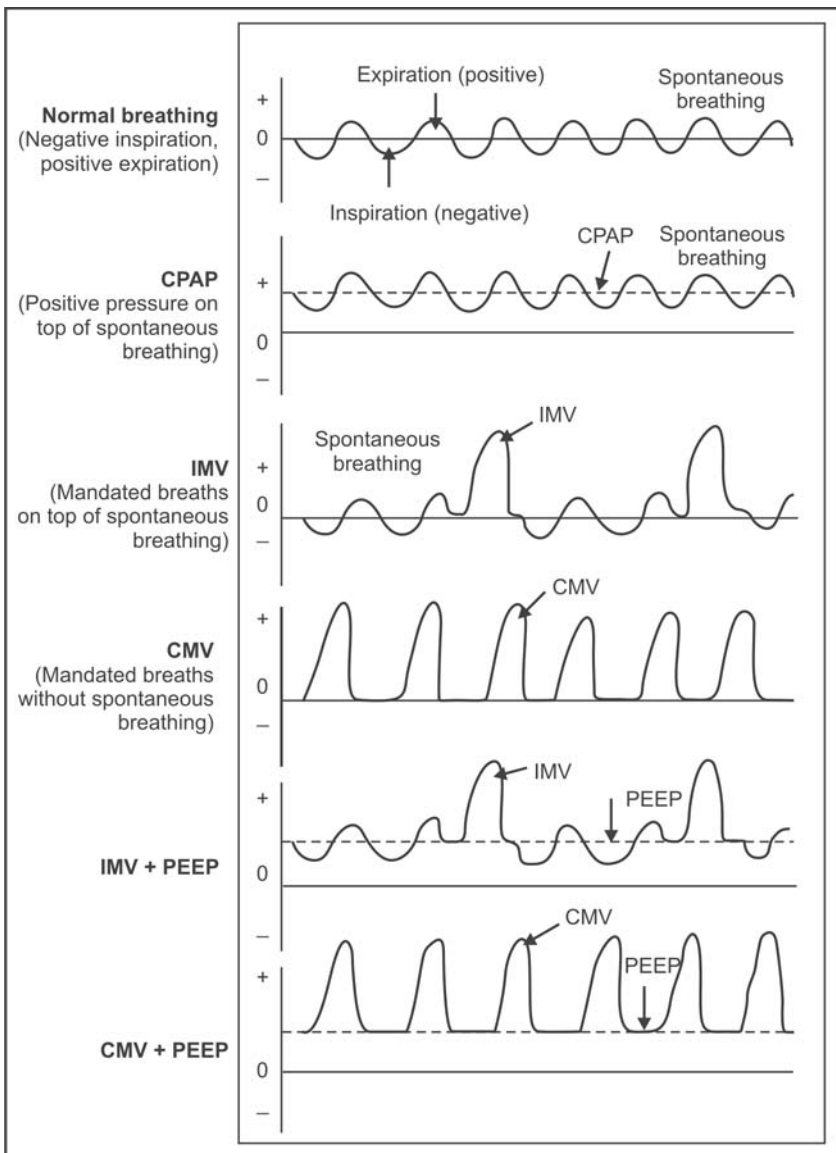


Fig. 6.6: Respiratory waveform in different modes of pressure support

Specific treatment

Treatment of the causative disease and the possible associated complications should go parallel to the nonspecific respiratory support. For instance, decompression of the collapsed lung by closed intercostal drainage is lifesaving in case of pneumothorax or massive pleural effusion. Bronchodilator therapy (given by aerosol, I.V. or subcutaneous route) may result in rapid improvement in case of acute asthma. Proper choice and appropriate dosage of antibiotic therapy in pneumonia can greatly affect the outcome. In pulmonary edema and adult respiratory distress syndrome, identification and treatment of the precipitating disease is very important in addition to the nonspecific respiratory support. In organic phosphorus poisoning, atropine therapy is life-saving.

Specific treatment of the cause of distress

Pneumonia

Combined parenteral antibiotic therapy (in bacterial pneumonia).
Parenteral antifungal therapy with fluconazole (in candida pneumonia).
Oral co-trimoxazole in suspected pneumocystis carinii pneumonia.

Acute bronchiolitis

Antiviral therapy with ribavirin may be considered in extremely severe cases.

Acute asthma

Bronchodilator therapy (by aerosol, I.V., subcutaneous or oral route).

Pneumothorax

Diagnostic needle: Thoracocentesis (second intercostal space, mid-clavicular line).
Closed chest drainage (5th intercostal space, midaxillary line).

Pleural effusion

Diagnostic needle: thoracocentesis (5th intercostal space, midaxillary line).
Closed chest drainage (5th intercostal space, midaxillary line).

Pulmonary edema

Fluid restriction and diuretics.
Treatment of the causative disease.

Adult respiratory distress syndrome (ARDS)

Treatment of septic shock (dopamine infusion, antibiotic therapy).

Pneumonia

Pneumonia is a common and serious lower respiratory infection characterized by inflammation and consolidation of the alveoli, interstitial tissues or both (i.e. inflammation of parts responsible for gas exchange).

DIAGNOSIS

Pneumonia should be considered in every case of acute cough and respiratory distress especially when it is associated with fever. Diagnosis should include the pathological type, causative organism and complications.

1. **Pathological type:** It can be lobar, bronchopneumonia or interstitial pneumonia.
 - a. **Lobar pneumonia:** It is usually unilateral and the infection is limited to one lobe or lobule. The main auscultatory findings are bronchial breathing and increased vocal resonance over the involved lobe. Fine crepitations may be heard and some dullness is usually present. It is mostly bacterial in origin.
 - b. **Bronchopneumonia:** It is usually bilateral and the main auscultatory findings are bilateral fine consonating crepitations mainly over the lower lobes. In severe cases with significant lower airway obstruction, generalized obstructive emphysema and expiratory wheezing occur and the condition may simulate acute viral bronchiolitis. It can be bacterial or viral. Bacterial bronchopneumonia is more serious and usually associated with high fever, toxic look and marked respiratory distress.
 - c. **Interstitial pneumonia:** It is usually bilateral and mostly viral. Clinically, it is characterized by severe spasmodic cough, significant respiratory distress with minimal chest signs, tendency to prolonged expiration and expiratory wheezing, and prolonged course over weeks.
2. **Causative organism:** Most cases of pneumonia are bacterial or viral. In bacterial pneumonia, the main causative organisms are pneumococci, staphylococci, streptococci and hemophilus influenza. Other serious organisms as *Klebsiella*, *E. coli*, *Pseudomonas* and bacteroids may also be responsible. Accurate diagnosis depends on isolation of the causative organism by blood culture or culture of tracheal aspirate. Viral pneumonia should be considered when the fever is mild or absent and the patient is not seriously sick. *Mycoplasma pneumonia* is characterized by lobar involvement and absent respiratory distress. Pneumocystis carinii pneumonia is considered in prematures, young infants, mechanically ventilated patients or immunocompromised patients.

Differentiating features between bacterial and viral pneumonias

	Bacterial pneumonia	Viral pneumonia
Pathological type	Lobar or bronchopneumonia	Bronchopneumonia or interstitial
Clinical data		
Temperature	High (above 39.5°C)	Mild or moderate (below 38.5°)
Toxicity	Marked	Minimal
Cough	Not severe	Severe and may be spasmodic
Complications	Common	Uncommon
Laboratory data		
Leukocytic count	Above 15.000 (granulocytes)	Below 15.000 (lymphocytes)
Bandemia	Common	Unusual
Toxic granulations	Common	Unusual
CRP	Elevated (above 20 mg/litre)	Normal
ESR	Elevated (above 30 mm/first hour)	Normal
Blood culture	May be positive	Negative
Chest X-ray	Lobar consolidation or Patchy infiltrate	Reticulonodular infiltrate or Parahilar peribronchial infiltrate

3. **Complications:** Several complications may occur especially in infants and young children. Complications are much commoner with bacterial pneumonias, and can be classified into 2 groups, pulmonary and extrapulmonary complications.

Complications of pneumonia

Pulmonary complications

- Pleural effusion, empyema or pyopneumothorax .
- Respiratory failure: Especially with severe bacterial bronchopneumonia in infants.
- Pulmonary edema: Especially with fulminant bacterial pneumonia.
- Lung abscess: Especially with klebsiella pneumonia or staphylococcal pneumonia.

Extrapulmonary complications

- Toxic myocarditis and acute congestive heart failure.
- Functional paralytic ileus (vomiting, abdominal distention).
- Septicemia and may be septic shock.
- Meningismus (neck rigidity) especially with upper lobe pneumonia.

MANAGEMENT

The clinical decision regarding the place and lines of management depends on the age of the patient, the pathological type, the degree of respiratory distress and the presence or absence of complications.

Home management

Children above the age of 4 - 6 years with lobar pneumonia and without an evident distress or complications can be managed at home as those with severe bacterial bronchitis. Oral sultamicillin (Unasyn) or co-amoxiclav (Augmentin) for 10 days is satisfactory. An oral second generation cephalosporin as cefuroxime (Zinnat) or cefaclor (Ceclor or Bacticlor) is an alternative. When mycoplasma pneumonia is considered, oral erythromycin for 10 days is the drug of choice.

Hospital management

Presence of respiratory distress is the main indication for hospitalization. Most infants and young children with pneumonia are distressed and need admission. Hospital management includes the following aspects:

1. **Monitoring:** Frequent monitoring of the degree of respiratory distress is essential. Respiratory rate, retractions, grunting, color and level of consciousness should be recorded every 1-2 hours. Continuous monitoring of arterial oxygen saturation with pulse oximeter is very helpful. Arterial or arterialized blood gases (ABG) are also important to assess the degree of hypoxemia and ventilatory functions. PaO_2 below 50 mm Hg indicates lung failure. Repeated measurement of ABG is particularly important in infants with severe bronchopneumonia. PaCO_2 above 60 mm Hg is an indication for mechanical ventilation.
2. **Initial investigations:** Complete blood count (CBC) and C-reactive protein (CRP) are important to differentiate bacterial from viral infections. Leukocytosis, bandemia

and elevated ESR and CRP should suggest bacterial pneumonia. Chest X-ray is also essential to identify the pathological type and to detect complications as pleural effusion or hydropneumothorax.

3. **Respiratory support:** Oxygen therapy, chest physiotherapy and suctioning are the main lines of respiratory support. *Oxygen therapy* is indicated in presence of respiratory distress. The method of administration depends on the age as well as the patient's tolerance. Infants can be successfully managed with the head box, while older children can receive oxygen with oxygen mask or nasal prongs. The concentration of oxygen required depends on the degree of respiratory distress and the level of PaO_2 . Practically, 40-60% oxygen is usually sufficient, and the subsequent changes will depend on the course of illness. *Positive pressure support* is mainly indicated in exceptionally severe and fulminant cases of bronchopneumonia in infants. The clinical criteria to initiate mechanical ventilation are cyanosis (in spite of 60% oxygen) or progressive deterioration of the level of consciousness. On laboratory level, arterial oxygen saturation below 85% or PaO_2 below 70 mm Hg (with 70% oxygen) or PaCO_2 above 60 mm Hg are indications for mechanical ventilation. In areas where facilities for intensive care are not available, intermittent manual ventilation with the bag and mask (Ambu bag) is an alternative.
4. **Antibiotic therapy:** All cases of severe pneumonia should be considered potentially bacterial and should receive parenteral antibiotics for 10 days. In infants and young children, a combination of two parenteral drugs seems reasonable. Ampicillin (100 mg/kg/day) and an aminoglycoside as gentamicin (6 mg/kg/day) are a satisfactory initial therapy. As an alternative, parenteral second-generation cephalosporin as cefuroxime (75-150 mg/kg/day) is recommended. In severe fulminant cases of bronchopneumonia, one of the third generation cephalosporins as cefotaxime or cefoperazone (100-200 mg/kg/day) can be used. When staphylococcal pneumonia is strongly suspected, vancomycin (40-60 mg/kg/day, I.V. in 3-4 divided doses) should be added. The available preparation is Vancocin vial (0.5 gm). When the possibility of pseudomonas infection is standing, antipseudomonal penicillin as piperacillin should be used. The subsequent change of antibiotic therapy depends on the clinical response and the result of sputum culture. The intravenous route is the preferable one, but I.M. injections can also be effective.
5. **I.V. fluid therapy:** In infants with moderate or severe distress, oral feeding is hazardous and may lead to serious aspiration. Maintenance I.V. fluid therapy is usually needed during the first 2 - 3 days to provide an adequate fluid intake. If the patient is still having a significant distress, nasogastric tube feeding should gradually replace the I.V. fluid therapy. Oral feeding can be resumed in patients with no or minimal distress. The common mistake of allowing oral feeding to severely distressed infants should be avoided. On the other hand, keeping the infant on I.V. fluids only for more than 3 days should also be avoided.
6. **Management of complications:** With clinical suspicion of pleural effusion (empyema), radiological confirmation and diagnostic aspiration are the initial steps and the sample should be sent for culture and sensitivity studies. Closed intercostal

drainage (underwater seal) is then indicated in cases with massive or moderate effusion and the tube is left in place until complete drainage and complete expansion of the collapsed lung which is usually achieved within 2 - 5 days. In cases complicated with bronchopleural fistula, the tube should be left until complete healing of the fistula, which may occur over few weeks. The diagnosis of bronchopleural fistula depends on observing a "bubbling" in the glass of the under water seal during crying or deep respiration. It is important to mention that the ultimate prognosis of empyema in children is excellent and chest surgery is almost never necessary. Even in cases complicated with pleural thickening, fibrothorax or chest deformity, complete recovery will occur over few months. Myocarditis and congestive heart failure may occur especially in infants with severe bacterial bronchopneumonia. Parenteral digoxin therapy (loading and maintenance) is indicated for 2 - 4 days. The total fluid intake should be reduced by about 20-30%. Paralytic ileus may occur on severe pneumonia especially in infants. Vomiting and abdominal distension are the main clinical findings. Plain X-ray on the abdomen (in erect position) will show multiple fluid levels. The patient should be kept on maintenance I.V. fluid therapy with complete rest of the gastrointestinal tract. The condition usually subsides within few days and gradual oral feeding can be resumed.

Acute bronchiolitis

Acute bronchiolitis is a common interstitial pneumonia that causes inflammatory obstruction of the small airways (lower airway obstruction). It mainly occurs in infants with a peak incidence around the age of 6 months (3 months - 2 years). Respiratory syncytial virus is the main causative organism. Other viruses (as adenovirus or parainfluenza viruses) or mycoplasma infection may also be responsible.

DIAGNOSIS

The possibility of acute bronchiolitis should be considered in any infant (around the age of 6 months) with acute respiratory distress and expiratory wheezing. A history of contact to older children or adults with mild respiratory illness is usually obtained. The course of illness runs through 3 stages, each for few days:

- a. Nasopharyngitis and fever:** The illness starts with mild to moderate fever (38.0 - 39.5°C) and nasal discharge for few days.
- b. Respiratory distress and wheezing:** The infant rapidly develops the features of respiratory distress with rapid respiration (respiratory rate is 60 - 80/minute) and retractions. Cough is present and may be prominent. Chest auscultation reveals expiratory wheezing. Fine crepitations at the end of inspiration and beginning of expiration may be heard and air entry may be diminished in severe cases. Areas of bronchial breathing due to segmental collapse can be heard in 30% of cases. This stage usually lasts for few days but prolonged course may occur with adenovirus infection.

c. **Rapid improvement:** Within few days, manifestations of respiratory distress and wheezing disappear but cough may remain for another week.

- The most serious complications are respiratory failure and dehydration. Therefore, hospitalization, oxygen therapy and I.V. fluid therapy are the main lines of management.
- Prognosis is generally good. Mortality rate does not exceed 1% and is mostly related to adenovirus infection. It is important to remember that the illness, on the other extreme, can be mild and presenting only with mild wheezing and without distress.
- Chest X-ray reveals a hyperinflated chest (generalized obstructive emphysema). Areas of segmental collapse may also be present. Chest X-ray is also useful to differentiate the condition from bronchopneumonia. CBC and CRP are also useful in differentiation in doubtful cases.
- In one third of cases, a second or even a third attack may occur later. In this group, the possibility of developing bronchial hyper-reactivity and asthma is considerable especially in those with positive family history.

Acute bronchiolitis should not be confused with other causes of acute respiratory distress and expiratory wheezing.

Causes of acute respiratory distress and expiratory wheezing

Acute bronchiolitis

An infant around the age of 6 months.
The illness runs through 3 stages.
CBC and CRP are near normal.

Severe bacterial bronchopneumonia with generalized obstructive emphysema

Fever and toxic look are prominent.
Crepitations are more evident than wheezing.
Polymorphonuclear leukocytosis and elevated CRP are common.

Acute asthmatic episode

History of repeated attacks.
Commoner in children above 3 years.
Good response to bronchodilators.

Foreign body inhalation

Sudden onset associated with coughing and choking.
No preceding illness.
No response to bronchodilators.

Acute congestive heart failure

Triad of tachycardia, tachypnea and tender liver.
Cardiac murmurs may be heard.

Organic phosphorus poisoning

Pinpoint pupil.
Profuse bronchial secretions.
Associated lacrimation, salivation and disturbed consciousness.

MANAGEMENT

Management of acute bronchiolitis begins with the clinical decision of whether the case is for home or hospital management. The decision depends on the degree of respiratory distress and the ability to tolerate oral feeding.

Home management

Mild cases characterized by expiratory wheezing and minimal or no distress can be managed at home. Oral mucolytics and excess fluid intake are the only required lines of therapy. Oral dexamethasone for few days may also be added in more severe cases to reduce the mucosal edema. Re-examination after 1-2 days is essential to evaluate the course of illness and to identify severe cases requiring hospital management.

Hospital management

Severe cases characterized by severe respiratory distress and difficult oral intake should be hospitalized for few or several days. Hospital management includes the following aspects:

1. **Oxygen therapy:** Humidified oxygen can be given by a head box or a Venturi oxygen mask with a concentration of 40-60%. Subsequent change in concentration depends on the degree of hypoxemia and the degree of respiratory distress. Repeated measurement of blood gases is important to identify the exceptional extremely severe cases, which may necessitate mechanical ventilation. Repeated or continuous monitoring of arterial saturation by pulse oximeter is also very useful. Value below 90% is an indication of oxygen therapy and value below 85% in spite of 70% oxygen is an indication for positive pressure support.
2. **I.V. fluid therapy:** Maintenance I.V. fluid therapy for 2-3 days is important to prevent dehydration. Oral feeding can be gradually resumed from the third day with no need for nasogastric feeding.
3. **Drug therapy:** The role of drugs in management of acute bronchiolitis is doubtful and controversial.
 - a. **Bronchodilators:** Adrenaline given subcutaneous (0.01 mg/kg/dose) may be useful in reducing mucosal edema by its alpha adrenergic effect. Salbutamol, given by nebulization (0.25-0.5 ml of the drug added to 2-3 ml saline), can be given empirically and some infants may benefit from it. Theophylline should be avoided as it increases oxygen requirements.
 - b. **Corticosteroids:** Although they are generally not useful, they may be tried in severe critical cases to reduce mucosal edema especially when the possibility of adenovirus infection is likely. Hydrocortisone is given I.V. in a dose of 5 mg/kg/dose every 6 hours for 2-3 days. Dexamethasone can be used as an alternative.
 - c. **Antibiotic therapy:** It is not routinely indicated. However, it may be used in critically sick febrile patients with the possibility of superimposed bacterial infection.

4. **Mechanical ventilation:** Fortunately, the overall prognosis is excellent and more than 95% of cases will show dramatic improvement over 2-3 days. In 1% of cases, rapid deterioration occurs and mechanical ventilation for few days is life-saving. Continuous positive airway pressure (CPAP) may be effective but intermittent mandatory ventilation (IMV) should be used with CPAP failure or CO₂ retention.

Acute asthma

Bronchial asthma is the most common chronic illness in children. It is estimated that 5-10% of children experience episodic (paroxysmal) wheezing. The basic decisive factor in pathogenesis is the chronic bronchial hyperactivity, which is proportionate to the degree of severity of asthma.

DIAGNOSIS

Diagnosis of bronchial asthma is mainly clinical and depends on the presence of repeated attacks of expiratory wheezing. Although it mainly occurs in children above 2 years, infants also may be affected. However, wheezing in infants should stimulate the search for other causes (see acute bronchiolitis).

Diagnosis of acute asthma (or acute asthmatic episode) should include the severity of the acute attack as well as the precipitating factors or the triggering stimuli.

Severity of the acute asthma

Clinical assessment of the severity of the acute attack is very important for the clinical decision regarding the place and line of management.

Clinical grades of acute asthma

Grade I: Mild acute asthma (Wheezing only)

Prolonged expiration and expiratory wheezing are the main findings.
No respiratory distress or diminished air entry.
These patients can be safely managed at home.

Grade II: Moderate acute asthma (Wheezing and tachypnea)

Prolonged expiration and expiratory wheezing.
Rapid respiration (tachypnea) and slightly diminished air entry.
These patients can be managed at home but preferably in hospital.

Grade III: Severe acute asthma (Wheezing and retractions)

Prolonged expiration and expiratory wheezing.
Rapid respiration, retractions (intercostal, suprasternal) and moderately diminished air entry.
Pulsus paradoxus can be detected (more than 15 mm Hg).
These patients should be hospitalized, preferably in an intensive care unit.

Grade IV: Profound acute asthma (Wheezing and cyanosis)

Rapid respiration, marked retractions and cyanosis.
Markedly diminished air entry.
Wheezing is minimal or even absent. "Silent chest" or "tight chest".
These patients should be admitted to an intensive care unit.

- * Clinical assessment in hospitalized children should be combined with measurement of arterial oxygen saturation and blood gas analysis for proper assessment of ventilatory functions.

Cause of the acute attack

Bronchial asthma is not a single disease. The triggering stimuli that precipitate the acute attack (asthma triggers) are different from patient to patient. Even in the same patient, acute attacks may be precipitated by more than one stimulus. According to these triggers or stimuli, asthma is classified as:

1. **Viral-induced asthma:** Viral respiratory infections as common cold or bronchitis are the triggering precipitating factor in 40% of cases. The mechanism of mediator release is not through IgE. Pure viral-induced asthma is much commoner in infants and young children and terms as "wheezy bronchitis", "asthmatic bronchitis" or "wheezy infant" are commonly used. The prognosis for ultimate cure is good, as 70% of cases will remit completely in late childhood while 30% may turn to allergic asthma.
2. **Allergic asthma:** Respiratory allergy is the triggering precipitating factor in 50% of cases. The mechanism of mediator release is through IgE. The acute attacks are precipitated by exposure to pneumoallergens (as house dust, mites, pollen or fur) or less commonly to alimentary allergens (as eggs, fish, banana or chocolate). Viral respiratory infections may also precipitate the acute attacks. The condition is much commoner in children and prognosis for ultimate cure is less favorable than viral-induced asthma.
3. **Exercise-induced asthma:** Severe physical exercise can induce an acute attack in 30% of cases. The mechanism of mediator release is through airway cooling. It is characterized by moderate bronchospasm during exercise and severe bronchospasm after return to resting condition.

Other factors may also be responsible in some patients. *Environmental factors* (humidity, cold air, cigarette smoke or car exhaust fumes) and *emotional factors* (stress, anger or frustration) may aggravate the condition in some patients. Drugs as aspirin (aspirin-induced asthma) may be responsible.

MANAGEMENT

The use of bronchodilators is the mainstay in the management of the acute attack. The choice of the suitable drug or drugs, the route of administration and the place of management depend mainly on the severity of the acute attack and the age of the patient as well. Treatment can be summarized as follows:

- Mild attack: One bronchodilator (at home).
- Moderate attack: Two bronchodilators (at home).
- Severe attack: Two or three parenteral bronchodilators (in hospital).

Home management of mild to moderate attacks

Patients with mild to moderate attacks can be successfully managed at home. Therapy includes the following aspects:

1. **Bronchodilators:** The choice of the suitable drugs and the route of administration depend on the severity of the attack and the age of the patient:
 - **Mild attacks:** The use of **one** bronchodilator drug is usually sufficient.
 - In children below the age of 6 years, theophylline or a theophylline variant (15-20 mg/kg/day, oral, divided into 3-4 doses) or beta 2-agonist as salbutamol or terbutaline (0.1-0.3 mg/kg/day, oral, divided into 3 - 4 doses) are equally effective. Salbutamol can be given by nebulization (0.25-0.5 ml of the drug added to 2-3 ml saline), 3-4 times per day.
 - On the other hand, in patients above the age of 6 years, a beta 2-agonist as salbutamol, given by inhalation (aerosol therapy), is preferable and gives an immediate effect. The dose is one puff of the metered aerosol, 3 - 4 times daily. The child should be taught carefully how to use the aerosol and the technique should be repeatedly checked.
 - **Moderate attacks:** The simultaneous use of two bronchodilator drugs (theophylline + beta 2-agonist) is justified. Therapy with bronchodilators should be continued for 3 - 4 days after the child has become wheeze-free. The average duration of therapy is usually 7 - 10 days. In patients with moderate attacks and previous recent history of severe attack and hospitalization, a short course of oral corticosteroids for 4 - 5 days may be added.
2. **Antibiotics:** The use of antibiotics is not indicated and will not alter the course of illness. Even in cases precipitated by respiratory infections, the infection is almost always viral in origin. However, antibiotics may be justified in infants or in exceptional cases with high fever where the possibility of superimposed bacterial infection is considerable.
3. **Cough medicines:** The role of expectorants or cough suppressants in management of the acute attack is minimal. However, some of the preparations of salbutamol or terbutaline contain an expectorant as well (see bronchodilators). In exceptional cases with severe spasmodic cough, a cough suppressant may be used to allay anxiety.

Hospital management of acute severe attacks

- **In emergency department,** an initial management is made with oxygen therapy, subcutaneous adrenaline (0.01 mg/kg/dose) and salbutamol nebulization (0.25-0.5 ml of the drug added to 2-3 ml saline). Both drugs can be repeated after 20 minutes. When salbutamol nebulization is not available, salbutamol inhaler and a "spacer" can be used. Further management will depend on the response:

Evaluation of response to initial emergency department management

Parameter	Good response	Incomplete response	Poor response
Respiratory distress	Minimal	Mild to moderate	Severe
Pulsus paradoxus	Below 10 mm Hg	10- 15 mm Hg	Above 15 mm Hg
Oxygen saturation	Above 95%	90 - 95%	Below 90%

- In case of good response, salbutamol nebulization can be given every 2 hours for 2-3 doses and the patient can be then sent home and managed as those with a moderate acute attack (beta 2-agonist + theophylline + steroids).
 - In case of incomplete response, salbutamol nebulization is continued every 20 minutes for 3 doses and steroids (oral or parenteral) should be added. Ipratropium nebulization may also be considered (0.5-1.0 ml of the drug added to 3-4 ml saline). In case of favorable response, treatment can be continued as the group of good response. Failure of these measures necessitates hospitalization.
 - In case of poor response or in deteriorating cases, the patient should be hospitalized.
- Hospital management includes the following aspects:
1. **Close observation:** Heart rate, respiratory rate, degree of retraction, air entry, color and level of consciousness should be recorded every 1 - 2 hours.
 2. **Oxygen therapy:** Oxygen is essential to correct hypoxemia and to allay anxiety. Moreover, the use of bronchodilators will increase the oxygen requirements. The method of administration depends on the age of the patient. Head box is the most suitable for infants while in older children oxygen mask or nasal prongs can be used. The concentration of 40 - 60% oxygen is usually sufficient. When pulse oximeter is available, oxygen saturation should be kept above 90%. Oxygen should be given continuously and withdrawn gradually. Duration of oxygen therapy in acute severe asthma is usually 1-3 days.
 3. **I.V. fluid therapy:** Maintenance I.V. fluid therapy in the first day or two is important to provide an adequate fluid intake and to prevent dehydration. Oral feeding can be gradually resumed in the second or third day.
 4. **Drug therapy:** Three drugs can be used simultaneously:
 - **Nebulized salbutamol** (0.25-0.5 ml of the drug added to 2-3 ml saline) is continued every 1-2 hours. Ipratropium nebulization may also be considered (0.5-1.0 ml of the drug added to 3-4 ml saline).
 - **Theophylline** (5 mg/kg/dose, slow I.V., every 6 hours) is also given.
 - **Methyl prednisolone** is given (1-2 mg/kg/dose, I.V. every 6 hours). Dexamethasone can be given as an alternative in a dose of 0.25 mg/kg/dose, I.V. every 12 hours.

Treatment is usually continued for 2-3 days after which, the 3 drugs can be replaced by oral preparations for 5-7 days. Parenteral antibiotics are not generally indicated except in infants or when the possibility of superimposed bacterial infection is considerable, as in those with high fever, marked leukocytosis or significantly elevated C-reactive protein.
 5. **Mechanical ventilation:** Fortunately, more than 95% of acute severe attacks respond to the above lines and show significant improvement within 24- 48 hours. However, in case of clinical deterioration or when arterial blood gases reveal severe hypoxemia and CO₂ retention, endotracheal intubation and mechanical ventilation are indicated for 1-2 days.

Summary of hospital management of acute severe asthma

Emergency department management

Oxygen therapy (40- 60%) by head box or oxygen mask.

Subcutaneous adrenaline: 0.1 ml/kg of the diluted solution (1 ml + 9 ml saline).

Nebulized salbutamol: 0.25 - 0.5 ml of the drug added to 2 - 3 ml saline and given by a nebulizer and oxygen mask. When nebulizer is not available, use a salbutamol inhaler and a "spacer". In this case, the dose is 2 - 4 puffs/time.

Evaluate the response after 20 - 30 minutes.

Continue management according to the response (see above).

In patient ward (or intermediate care unit) management

(Indicated in case of poor response to emergency room management).

Close observation (including arterial oxygen saturation with pulse oximeter).

Oxygen therapy: 60-70% by head box or oxygen mask.

I.V. fluid therapy (maintenance therapy).

Drug therapy

Nebulized salbutamol: 0.25 - 0.5 ml added to 2-3 ml saline every 1 -2 hours.

I.V. Aminophylline: 5 mg/kg, slow I.V. every 6 hours (or 1 mg/kg/hour).

I.V. methylprednisolone: 1-2 mg/kg every 6 hours
(or I.V. dexamethasone: 0.25 mg/kg every 12 hours).

Continue management for 2 - 3 days, and then replace with oral drugs.

Intensive care unit (ICU) management

Indicated in extremely severe cases with CO₂ retention (PaCO₂ above 40 mm Hg) and oxygen saturation below 90% in spite of 60 - 70% oxygen therapy.

Continuous monitoring: HR RR, arterial oxygen saturation.

Oxygen therapy: Increase concentration to keep saturation above 90%.

I.V. fluid therapy: Same as ward management.

Drug therapy: Same as ward management

Mechanical ventilation: With marked CO₂ retention (PaCO₂ above 55 mm Hg), severe hypoxemia, severe acidosis or disturbed consciousness.

Pneumothorax

Pneumothorax is a serious life-threatening condition, which can be **spontaneous** (severe bronchiolitis, pertussis, interstitial pneumonia) or more commonly **iatrogenic** (vigorous manual ventilation, mechanical ventilation, chest surgery). In severe cases or with tension pneumothorax, obstructive shock can occur and may even cause cardiac arrest (see also cardiopulmonary resuscitation).

DIAGNOSIS

The possibility of pneumothorax should be considered in every case of respiratory distress and chest auscultation should start with comparison of air entry over both sides.

1. **Clinical diagnosis:** In addition, to respiratory distress, markedly diminished air entry and hyper-resonance over the involved side with mediastinal shift to the other side are the main clinical findings.

2. **Chest transillumination:** In neonates and young infants, transillumination of the chest with a cold light source can be useful where a pneumothorax may show a hyper-illuminating area.
3. **Chest X-ray:** An urgent chest X-ray is diagnostic and it reveals a hypertransradiant hemithorax with absent bronchovascular markings and mediastinal shift to the other side.

MANAGEMENT

Urgent management of pneumothorax is essential to avoid serious complications as obstructive shock and cardiac arrest.

1. **Needle thoracocentesis:** When tension pneumothorax is strongly suspected, needle thoracocentesis can be lifesaving and can be performed with minimal equipment. A large I.V. cannula (16 - gauge) attached to a 20 ml syringe is inserted vertically into the chest wall of the affected side in the second intercostal space, in the mid-clavicular line, just above the rib below. If air is aspirated, remove the needle and leave the cannula in place, and proceed to closed-chest drainage as soon as possible. On the other hand, if the patient is not having tension pneumothorax (no aspirated air), the cannula is removed and a chest X-ray should be done because needle aspiration may cause pneumothorax in 10 - 20% of cases.

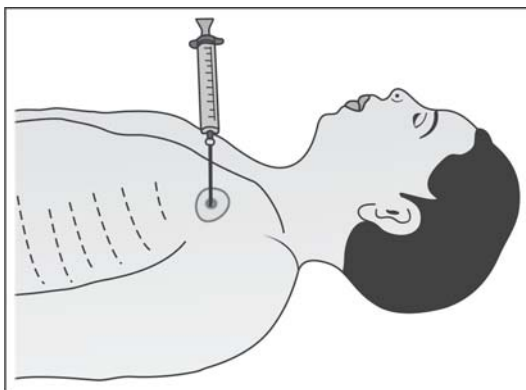


Fig. 6.7: Needle thoracocentesis

2. **Closed chest drainage:** When time allows, closed chest drainage by under water seal is the treatment of choice. The technique of tube insertion is done by a surgeon under local anesthesia. A small incision 2 - 3 cm long is made along the line of intercostal space in the fifth intercostal space in the mid-axillary line. Following dissection through the subcutaneous tissue, a chest tube of appropriate size is inserted into the pleural space and the other end of the tube is connected to underwater seal. The tube should remain in place until complete expansion of the collapsed lung. Temporary closure of the tube for several hours (6-12 hours) should be made before removal of the tube to ensure adequate lung expansion.

It is important to note that small pneumothorax (less than one third of hemithorax) not associated with respiratory distress should be left for spontaneous absorption over few or several days.

7 Chapter

Hypoventilation (Pump Failure)

Diagnosis of pump failure (or hypoventilation)

Clinical diagnosis

Central respiratory depression: Coma + shallow slow respiration ± apneic spells.

Respiratory muscle paralysis: Paralysis + shallow rapid respiration ± paradoxical breathing (see saw movements) with diaphragmatic paralysis.

Respiratory muscle fatigue: Severe respiratory distress + altered consciousness due to CO₂ retention.

Laboratory diagnosis

Blood gases: Hypoventilation (CO₂ retention + respiratory acidosis).

Pulmonary function: Low tidal volume (less than 6-8 ml/kg) and minute ventilation.

Causes of pump failure

Central respiratory depression: All causes of coma, central hypoventilation syndrome.

Respiratory muscle paralysis: Poliomyelitis, Guillain Barre syndrome, botulism.

Respiratory muscle fatigue: All causes of severe respiratory distress.

Management of pump failure

Nonspecific respiratory support

Chest physiotherapy and suctioning.

Mechanical ventilation.

Treatment of complications.

Specific management

Drug therapy: Theophylline, naloxone, I.V. immunoglobulins, neostigmine.

Plasmapheresis: In Guillain Barre syndrome.

Phrenic nerve stimulation: In central hypoventilation syndrome.

Respiratory weakness (or hypoventilation) occurs due to functional impairment of the respiratory pump. The respiratory pump is the system responsible for ventilation or air movement inside (inspiration) and outside (expiration) the lungs.

The respiratory pump system consists of the brain (the controller) and the respiratory neuromuscular system (the machine).

- **In the brain**, cerebral cortex is responsible for voluntary control while the pons and medulla maintain involuntary control of respiratory rhythm. These controllers are influenced by chemoreceptors (from cranial nerve IX) and stretch receptors from intercostals nerves.
- **Respiratory neuromuscular system** is responsible for chest movements and is composed of spinal cord, respiratory nerves and respiratory muscles (inspiratory and expiratory muscles).

Components of the respiratory pump

Brain (The central controller)

Cerebral cortex: Responsible for voluntary control.

Brainstem (Pons and medulla): Responsible for involuntary control.

Respiratory neuromuscular system

Spinal cord.

Respiratory nerves and muscles

Cervical nerves (C2 - C4): Accessory muscles.

Phrenic nerve (C3 - C5): Diaphragm.

Intercostal nerves (T1 - T12): Intercostal muscles.

Lower thoracic nerves (T6 - L2): Abdominal muscles.

- Muscles of inspiration are the diaphragm, external intercostal muscles and the accessory muscles while muscles of expiration are the abdominal muscles and internal intercostal muscles.
- Cranial nerves IX (Pharynx), X (larynx) and XII (tongue) are responsible for airway patency.

DIAGNOSIS

Respiratory weakness or hypoventilation results from any lesion in the respiratory pump and may lead to respiratory pump failure. This type can be diagnosed clinically and the diagnosis can be confirmed by blood gas analysis.

1. Clinical diagnosis: The possibility of hypoventilation should be considered in three main clinical situations; (1) comatose patients, (2) acute paralysis or chronic motor weakness and (3) severe respiratory distress. The clinical manifestations of hypoventilation vary according to the clinical presentation and the mechanism of hypoventilation.

- In central respiratory depression*, the main clinical presentation is coma, which may occur due to primary or secondary brain disease. The main manifestation of hypoventilation is shallow slow respiration. Apneic spells or even terminal apnea (respiratory arrest) may occur in severe cases due to brainstem dysfunction. A special entity that deserves mentioning is the central hypoventilation syndrome or "Ordine's curse" which is characterized by apnea that occurs only during sleep (sleep apnea).
- In respiratory muscle paralysis*, the main clinical presentation is acute paralysis or chronic motor weakness. Manifestations of hypoventilation include shallow rapid breathing and inability to speak without frequent pauses. Paradoxical breathing occurs with diaphragmatic paralysis, where the abdomen collapses during inspiration and distends during expiration (see saw abdominal movements).
- In respiratory muscle fatigue*, the main clinical presentation is severe respiratory distress extending over several hours or days. It is the most common cause of hypoventilation and can be considered as a complication of severe lung failure.

Clinical manifestations of hypoventilation can be indirectly expected in severe cases by the depressed consciousness due to marked CO_2 retention.

2. **Arterial blood gases:** Clinical diagnosis of hypoventilation should be confirmed by the presence of respiratory acidosis (CO_2 retention, \pm low pH, normal or high HCO_3^-). According to the degree of CO_2 rise, hypoventilation may be divided into mild (PaCO_2 between 45 - 50 mm Hg), moderate (PaCO_2 between 50 - 60 mm Hg) and severe (PaCO_2 above 60 mm Hg). With severe hypoventilation (PaCO_2 above 60 mm Hg), altered consciousness occurs (CO_2 narcosis). In acute hypoventilation, CO_2 retention is accompanied with proportionate lowering of pH while in chronic hypoventilation, CO_2 retention is usually associated with a near normal pH (see also acid-base disorders).
3. **Pulmonary function:** When facilities to measure lung volumes are available, measurement of tidal volume (normal value is 6-8 ml/kg) and minute ventilation (tidal volume X respiratory rate) are very useful for diagnosis of hypoventilation where both values are significantly reduced. In severe cases, tidal volume may be only 1 - 2 ml/kg. These measurements can be made by "closed-circuit spirometer" or "body plethysmography". Body plethysmography is very expensive equipment, which can measure different lung volumes and capacities in addition to lung compliance, airway resistance and time constant (compliance X resistance).

Laboratory diagnosis of hypoventilation

Respiratory acidosis: High PaCO_2 (above 45 mm Hg) and low pH (in acute conditions).
Low tidal volume (below 5 ml/kg) and low minute ventilation.

Cause of hypoventilation

Identification of the cause of hypoventilation is important for diagnostic, prognostic and therapeutic reasons. However, full description of different diseases causing hypoventilation is beyond the scope of this chapter. Classification of causes into three categories is practically useful as treatment of hypoventilation in these categories is somewhat different.

Causes of hypoventilation

Central respiratory depression

Primary brain lesion: Hemorrhage, infection, convulsions.
Secondary brain lesion: Hypoxic encephalopathy, CNS depressant drugs.
Central hypoventilation syndrome or Ordine's curse: Congenital or acquired.

Respiratory muscle paralysis

Acute: Poliomyelitis, Guillain Barre syndrome, botulism, spinal cord trauma, phrenic nerve injury.
Chronic: Werdnig-Hoffmann disease, myasthenia gravis, muscular dystrophies.

Respiratory muscle fatigue

Severe pneumonia, severe acute bronchiolitis, severe acute asthma.
Other pulmonary causes of respiratory distress.

1. **Central respiratory depression:** In patients presenting with coma, careful history (trauma, fever, drug intake), complete examination (neurological and systematic) and relevant investigations (laboratory and radiological) can help to identify the causative disease. In central hypoventilation syndrome characterized by apnea during sleep, the illness can be congenital (onset in neonatal period or early infancy) or acquired (idiopathic or following encephalitis, severe hypoxia, medullary infarction or posterior fossa tumor). The condition should not be confused with obstructive apnea, which is also characterized by apnea during sleep. In obstructive apnea, the cause is usually evident as hypertrophied tonsils and adenoids, macroglossia (Down syndrome), micrognathia (Pierre Robin syndrome), paralysis of vocal cords or other oral and nasal deformities. Proper evaluating of patients with this disease requires continuous monitoring (during sleep) of HR, RR, arterial oxygen saturation and EEG.
2. **Respiratory muscle paralysis:** In patients presenting with acute paralysis, the distribution and sequence of paralysis are very useful in differentiation between different diseases.
 - a. **Poliomyelitis:** It is a viral disease of anterior horn cells, which mainly occurs in unvaccinated or partially vaccinated infants and young children. Paralysis is sudden, massive and asymmetric. It usually starts in lower limbs and ascends to involve the trunk and upper limbs. Respiratory and bulbar paralysis may occur in severe cases. Gradual, but incomplete recovery usually occurs over 6 months. Residual wasting, shortening and deformities usually occur in severe neglected cases. Now, the disease is extremely rare.
 - b. **Guillain Barre syndrome:** It is by far the commonest cause of acute paralysis especially in children above the age of 3 years. It is an immune peripheral neuritis following a viral infection. Paralysis is acute and symmetric. It starts in lower limbs and usually ascends over few days to involve the trunk and upper limbs (tetraplegia). Bulbar paralysis occurs in 50% of cases. Respiratory paralysis occurs in 20% of cases and necessitates hospitalization and prolonged mechanical ventilation for weeks. Confirmatory investigations include nerve conduction velocity (markedly reduced) and CSF examination after 2 weeks of onset (increased CSF proteins). The course is benign in most cases and gradual complete recovery usually occurs over few weeks or few months.
 - c. **Botulism:** It is a toxic neuromuscular blockade caused by the anaerobic clostridium botulinum. Infection usually follows ingestion of improperly home-preserved foods containing the toxins. Paralysis is acute, symmetric and descending. It starts in bulbar nerves then descends over a period of few hours or few days to involve the trunk and limbs. Respiratory paralysis is common and usually necessitates prolonged mechanical ventilation. Other clinical findings include dry mucous membranes of mouth, tongue and pharynx. The course of illness is prolonged over several weeks. CSF and nerve conduction velocity are normal (important differentiating points from the descending type of Guillain

Barre syndrome). The most important diagnostic investigation is electromyography, which demonstrates the characteristic brief, small, abundant motor-unit action potential (BSAP).

- d. **Spinal cord trauma:** Severe trauma to the back may cause spinal cord injury and acute paralysis. Respiratory paralysis only occurs when the lesion is in the cervical cord. High cervical lesions (C1-C2) result in apnea and early death while middle cervical lesions (C3-C5) result in respiratory muscle paralysis (diaphragm, intercostals, abdominal muscles).
 - e. **Phrenic nerve injury:** Direct trauma to the phrenic nerve may occur during thoracic surgery and results in unilateral diaphragmatic paralysis. While older children and adults can tolerate the loss or hemidiaphragmatic function, infants usually suffer from a severe respiratory dysfunction.
3. **Respiratory muscle fatigue:** In patients presenting with respiratory distress, careful history, proper examination and some investigations can guide towards the correct diagnosis. Severe pneumonia, acute bronchiolitis and severe acute asthma are the most common causes.

MANAGEMENT

Management of hypoventilation depends on the severity of the condition, the causative disease and the possible associated manifestations or complications. Management can be classified into nonspecific respiratory support and specific management.

Nonspecific respiratory support

It aims to improve ventilation and to treat the possible associated complications:

1. **Chest physiotherapy and suctioning:** These simple physical measures are useful to mobilize secretions, to clear the alveoli and airways and to improve alveolar ventilation. In older children with respiratory muscle paralysis, deep breathing exercises are helpful to enhance recovery and to prevent respiratory muscle wasting. Effective physiotherapy may save many patients with moderate hypoventilation from being mechanically ventilated.
2. **Mechanical ventilation:** The indication to start mechanical ventilation depends on the disease category and the causative disease:
 - a. In comatose patients due to primary brain lesion, early mechanical hyper-ventilation is indicated to keep PaCO_2 just below 30 mm Hg. The reduction of PaCO_2 level is therapeutic and it aims to reduce the cerebral blood flow and the commonly associated increased intracranial pressure (as PaCO_2 has a direct relation to cerebral blood flow, any increase or decrease in PaCO_2 is associated with concomitant increase or decrease in cerebral blood flow).
 - b. In comatose patients due to CNS depressant drugs, mechanical ventilation is only indicated when PaCO_2 exceeds 60 mm Hg or when apnea occurs. As the condition is transient, intermittent manual ventilation with the bag and mask for few minutes every 15 - 20 minutes is an alternative.

- c. In patients with acute respiratory muscle paralysis as Guillain Barre syndrome, mechanical ventilation is indicated only in severe cases of hypoventilation with PaCO_2 above 60 mm Hg or tidal volume below 3 ml/kg. As mechanical ventilation in these cases may extend over several weeks, tracheostomy is preferable than endotracheal intubation. It is important to remember that in these patients there is no defect in oxygenation, therefore, mechanical ventilation should be made with minimal or no oxygen therapy. Weaning from ventilation should be very gradual and deep breathing exercises are important to prevent muscle fatigue.
 - d. In patients with chronic progressive respiratory muscle paralysis as Werdnig-Hoffmann disease and muscular dystrophies, the decision to ventilate or not is a difficult ethical problem. The parents of the patient should share in arriving the decision to start chronic lifelong mechanical ventilation or not. Although mechanical ventilators designed for home use are available, the eventual outcome is death after several months or few years. Some arguments against ventilation are based on the view that "the ventilator used to prolong life in a patient with chronic progressive fatal disease can be used to save lives of several patients with acute reversible conditions". However, it is important to note that transient mechanical ventilation for acute respiratory problems on top of chronic weakness may be justified as many patients successfully overcome these acute episodes.
 - e. In patients with respiratory muscle fatigue due to severe lung pathology, mechanical ventilation can be started when PaCO_2 exceeds 50 mm Hg or 60 mm Hg. Duration of ventilation depends on the causative disease. It may be only few days (acute asthma or acute bronchiolitis), several days (pneumonia) or several weeks (bronchopulmonary dysplasia or adult respiratory distress syndrome).
3. **Treatment of complications:** Patients with hypoventilation, especially those with respiratory muscle paralysis are susceptible to several complications:
- a. **Respiratory complications:** Pneumonia, lung collapse and repeated aspiration are common due to the inability to cough effectively and the commonly associated bulbar palsy. These complications should be prevented by chest physiotherapy, suctioning and careful nasogastric tube feeding. Pneumonia should be urgently managed with the appropriate antibiotic therapy.
 - b. **Bed sores** are common due to prolonged immobilization and it should be prevented by frequent change of position, frequent change of wet diapers and care of the skin.

Specific management

Some specific measures for certain diseases can be used in selected situations.

1. **Drug therapy:** *Theophylline* (15 mg/kg/day, oral in divided doses) can be used as a respiratory stimulant of medullary centers in patients with central hypoventilation syndrome. It may also be used as a stimulant to respiratory muscles to delay the occurrence of muscle fatigue in patients with chronic distress as bronchopulmonary

dysplasia. Naloxone (0.1 mg/kg/dose, I.V.) can be used as a respiratory stimulant in patients with CNS depression due to opiate overdosage. As the drug is short-acting, the dose can be repeated every 1 - 2 hours for up to 3 doses.

It is important to remember that respiratory depression may follow high doses of cough suppressant drugs containing codeine. Intravenous immunoglobulins (300 mg/kg, I.V. infusion over 6 - 8 hours for 4 - 5 days) can be used in early days of Guillain-Barre syndrome. Neostigmine is used for muscle weakness in myasthenia gravis.

2. **Plasmapheresis:** It is recommended in severe cases of Guillain Barre syndrome especially when associated with respiratory paralysis. Plasmapheresis involves the separation of plasma from cellular components of blood by centrifugation or filtration. The plasma is replaced with a crystalloid and albumin mixture added to the blood cells and is returned to the body. Plasmapheresis may enhance recovery and shorten the time of mechanical ventilation. The optimal effect can be expected if plasmapheresis is used during the first week of illness. When plasmapheresis is not available, exchange blood transfusion can be used as an alternative.
3. **Phrenic nerve stimulation:** Radiofrequency bilateral phrenic nerve pacing can be used in patients with central hypoventilation syndrome. The technique depends on subcutaneous implantation of a radio-frequency receiver, which receives excitation from an external radio signal generator. It is important to note that in symptomatic patients with unilateral phrenic nerve injury, surgical plication of the injured nerve and positive pressure support are the main lines of therapy, and phrenic nerve stimulation has no place in this illness.



Fig. 7.1: Mechanical ventilation in 4 years old boy with Guillain Barre syndrome



Fig. 7.2: Plasmapheresis in 4 years old boy with Guillain Barre syndrome



Section 3

Cardiovascular Emergencies

- Acute Congestive Heart Failure
- Circulatory Failure (Shock)
- Cardiac Arrhythmias
- Cardiac Tamponade
- Duct-dependent Congenital Heart Disease
- Paroxysmal Hypercyanotic Attacks (Cyanotic Spells)
- Systemic Hypertensive Crisis
- Acute Pulmonary Hypertension
- Postoperative Cardiac Surgery

8 Chapter

Acute Congestive Heart Failure

Clinical grading of acute congestive heart failure

Grade I (Heart failure only)

Clinical triad of tachycardia, tachypnea and enlarged tender liver

Grade II (Heart failure and respiratory failure = Pulmonary edema)

Marked distress (intercostal retractions) with fine or coarse crepitations

Grade III (Heart failure and circulatory failure = Cardiogenic shock)

Severe hypotension with poor peripheral perfusion (cold extremities, skin mottling)

Causes of acute congestive heart failure

Preload failure (volume overload)

Acute renal failure
Excess I.V. fluids

Contractility failure (poor myocardial contraction)

Myocardial ischemia (hypoxia, shock)
Myocarditis (infective, rheumatic)

Afterload failure (pressure load)

Hypertension (as poststreptococcal glomerulonephritis)

Arrhythmic failure

Severe tachycardia (as paroxysmal supraventricular tachycardia)

Management of acute congestive heart failure

Treatment of heart failure

Oxygen therapy (to correct hypoxemia)
Digoxin therapy (to improve myocardial contractility)
Diuretic therapy (to reduce preload)

Treatment of pulmonary edema

Oxygen and diuretic therapy
Continuous positive airway pressure (CPAP)
Mechanical ventilation

Treatment of cardiogenic shock

Inotropic drug support (with I.V. infusion of dopamine, dobutamine or both)
Afterload reducing agents (as I.V. infusion of sodium nitroprusside)

Specific treatment

According to the causative disease

Heart failure is the inability of the heart to pump blood in an amount sufficient to the body requirements. According to the mechanism of dysfunction heart failure can result from the following:

- a. *Contractility failure*: It results from *poor myocardial contraction* as in myocarditis, myocardial ischemia and cardiomyopathy.
- b. *Preload failure*: It results from volume load on the right side of the heart as in hypervolemia (acute renal failure, excess I.V. fluids) or big left-to-right shunt (ASD, VSD, PDA).
- c. *Afterload failure*: It results from pressure load on the left side of the heart as in hypertension or left side obstruction (coarctation, AS).
- d. *Arrhythmic failure*: It occurs due to *extreme changes in heart rate* that decrease the cardiac output as in extreme tachycardia (low stroke volume) or extreme bradycardia (slow heart rate).

Types of heart failure

Clinically, congestive heart failure can be divided into acute and chronic.

1. **Acute congestive heart failure**: Clinical manifestations of cardiac dysfunction appear acutely and are well evident at rest. Progression of severity can be rapid leading to pulmonary edema or cardiogenic shock.
2. **Chronic congestive heart failure**: Clinical manifestations of cardiac dysfunction appear insidiously over several weeks or months and are not evident at rest in mild cases (see Pediatric clinical diagnosis).

In this chapter, discussion will be only limited to acute congestive heart failure (For chronic congestive heart failure, see Pediatric clinical diagnosis).

DIAGNOSIS

Diagnosis of acute congestive heart failure should include clinical grading of severity and identification of the underlying cause.

Types of heart failure

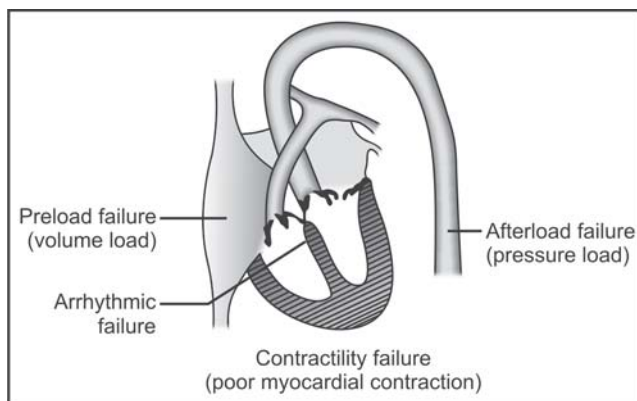


Fig. 8.1: Causes of acute congestive heart failure

Clinical grading of acute CHF

Clinical diagnosis of acute congestive heart failure depends on the presence of clinical triad of tachycardia, tachypnea and enlarged tender liver. Cardiomegaly is usually present but may be difficult to elicit clinically. In more advanced cases, marked pulmonary congestion occurs and leads to pulmonary edema and respiratory failure. In severe cases, marked reduction of cardiac output occurs and results in cardiogenic shock.

Clinical assessment of severity is important for the proper choice of the line of therapy and for monitoring the course of illness.

Clinical grading of acute congestive heart failure

Grade I: Heart failure only

Disproportionate tachycardia (disproportionate to age and temperature).
Disproportionate tachypnea (disproportionate to age and temperature).
Hepatomegaly (congested tender liver).
Cardiomegaly (well evident radiologically).

Grade II: Heart failure and respiratory failure (Pulmonary edema)

Moderate to severe respiratory distress (retractions, \pm cyanosis)
Expiratory wheezing, fine basal or coarse bubbling crepitations.
• Chest X-ray: Marked pulmonary congestion or pulmonary edema.
• Arterial blood gases: Low PaO₂ (below 50 mmHg), \pm high PaCO₂.

Grade III: Heart failure and circulatory failure (cardiogenic shock)

Peripheral hypoperfusion (mottled skin, cold extremities).
Hypotension (measurement of blood pressure is essential).
Vital organ hypoperfusion (kidneys, lungs, GIT, brain, heart).
• Doppler echocardiography: Reduced cardiac output.
• Pulmonary artery catheterization: Accurate measurement of cardiac output.

- Heart rate and respiratory rate should be counted over 1 minute in a quiet patient.
- Measurement of blood pressure is essential for detection of hypertension or shock.
- Distended neck veins, edema, gallop rhythm are variable findings and may be absent.
- Chest X-ray is useful for detection of cardiomegaly and pulmonary edema.
- ECG is useful for detection of arrhythmias and myocarditis.
- Echocardiography is useful for detection of poor contraction and endocarditis.
- Doppler echocardiography is useful for detection of low cardiac output.
- Arterial blood gases are essential for detection of respiratory failure.
- Pulmonary artery catheterization may be needed in cardiogenic shock.
- Evaluation of renal function is important because renal failure may be the cause of heart failure and, on the other hand, cardiogenic shock leads to renal failure.

Diagnosis of the cause

- **Clinical evaluation** should include the age, peripheral pulsations and presence of cardiac murmurs. At any age, myocarditis, myocardial ischemia, cardiac arrhythmias and acute renal failure can occur. Acute rheumatic carditis and acute poststreptococcal glomerulonephritis mainly occur above the age of 3-5 years. It should also be remembered that acute failure could occur on top of chronic failure caused by congenital or acquired heart diseases.

- **Relevant Investigations** include chest X-ray (to detect cardiomegaly and any special configuration), ECG (for detection of arrhythmias and myocarditis), echocardiography (for detection of anatomical and valvular lesions) and possibly Doppler echocardiography (for detection of vascular lesions as coarctation).

Value of echocardiography in cardiovascular emergencies

M-mode or two-dimensional echocardiography

- Detection of anatomical lesions (dimensions, valves, defects, vegetations).
- Detection of pericardial effusion in suspected tamponade.
- Evaluation of myocardial function.

Pulsed or continuous wave Doppler echocardiography

- Noninvasive measurement of cardiac output.
- Noninvasive diagnosis of pulmonary hypertension.
- Detection of abnormal flow as in coarctation and other congenital heart diseases.

- Doppler echocardiography can be used for continuous cardiac output measurement. This can be made by several techniques (transaortic, transtracheal, or transesophageal).
- Color Doppler is more accurate in assessment of the direction of intracardiac shunts. Flow towards the transducer is displayed red and flow away from the transducer is displayed blue.

MANAGEMENT

Patients with acute congestive heart failure should be hospitalized, preferably in an intensive care unit. Close observation and frequent monitoring of heart rate, respiratory rate, degree of distress, chest signs, color and level of consciousness are essential. Repeated measurement of blood pressure is also important to identify severe cases progressing to cardiogenic shock. Management includes the following aspects:

Treatment of acute CHF

1. **Bed rest:** Complete bed rest is indicated during the early critical stage. Most patients prefer the semi-sitting position. Activity can be gradually allowed after control of the condition.
2. **Feeding:** In severe cases accompanied with significant respiratory distress, oral feeding is hazardous especially in infants because of the risk of aspiration. A maintenance I.V. fluid therapy is mostly required during the first few days and the amount given should only equal 65 - 70% of the calculated amount. With persistent significant distress after the first few days of therapy, nasogastric tube feeding should gradually replace the I.V. fluids. Oral feeding can be resumed gradually as soon as the condition allows. In older children with mild failure, oral feeding can be allowed from the start.
3. **Oxygen therapy:** All patients with acute congestive heart failure should receive oxygen during the early critical stage to correct hypoxemia, to prevent myocardial

hypoxia and to decrease the work of breathing. The method of administration depends on the age of the patient. Infants can successfully manage with the head box while older children can receive oxygen with oxygen masks or nasal catheters. Initial oxygen concentration of 40% is usually sufficient. Frequent monitoring of arterial oxygen saturation with pulse oximeter is useful. Oxygen should be given continuously and should be withdrawn gradually (see oxygen therapy).

4. **Digoxin therapy:** Digoxin is the mainstay in management of acute and chronic congestive heart failure. It has an inotropic effect (increases myocardial contractility and improves cardiac output) and negative chronotropic effect (decreases the heart rate). In acute congestive heart failure, parenteral digoxin therapy (I.M. or preferably I.V.) is indicated in severe cases. The digitalizing dose (0.05 mg/kg) is divided into 3 doses (1/2, 1/4, 1/4, or 1/3, 1/3, 1/3). After the initial dose, the second and third doses are given after 8 hours and 16 hours respectively. In older children, the digitalizing dose should not exceed the adult dose (1.5 mg). The maintenance dose (0.01 mg/kg or 1/4 digitalizing dose) should start 24 hours after the initial digitalizing dose and should be divided into 2 equal doses (every 12 hours). As soon as the patient can tolerate oral feeding, the maintenance dose can be given orally. Available preparations of digoxin are; *Lonoxin digoxin amp. (0.5 mg/2 ml)*, *Digoxin tablets (0.25 mg)* and *Digoxin Pediatric elixir (0.05 mg/ml)*.

Precautions during digoxin therapy

- **Dose adjustment:** The digitalizing and maintenance doses can be slightly increased or decreased according to the response. In newborns and in late childhood, it is better to lower the digitalizing dose to 0.03-0.04 mg/kg. The dose should also be reduced in hypoxemia or associated renal disease.
- **Concomitant drug therapy:** Drugs as calcium or atropine should be avoided. When diuretics are concomitantly used, hypokalemia should be avoided, as it will lead to digitalis toxicity.
- **Measurement of serum digoxin level:** It is indicated when standard dosage is associated with unsatisfactory therapeutic response or when digitalis toxicity is clinically suspected. Therapeutic digoxin level is 2 - 4 ng/ml (in infants) and 1 - 2 ng/ml (in children).
- **Treatment of digitalis toxicity:** Early recognition of toxicity is important for immediate discontinuation of the drug and treatment of serious arrhythmias. ECG monitoring is important.
 - * **Atropine** (0.01 mg/kg/dose, I.V.) is effective in digoxin-induced sinus bradycardia or A.V. block of the second or third degree. The dose can be repeated within 5 minutes if necessary.
 - * **Phenytoin** (3- 5mg/kg/dose, I.V. over 5 minutes) is effective in digoxin-induced ventricular arrhythmias. The dose may be repeated every 10 minutes, when necessary, up to a total dose of 20 mg/kg.
 - * Electrolyte disturbances especially hypokalemia should be corrected.

5. **Diuretic therapy:** These drugs are used as preload reducing agents to reduce the circulating blood volume and pulmonary fluid overload. *Furosemide*, the most commonly used drug, is given initially in a dose of 1-2 mg/kg I.V. or I.M. The dose can be repeated after 12 hours if manifestations of pulmonary congestion are

prominent. With adequate control of the condition, the drug can be given orally in a dose of 1-2 mg/kg/day as a single dose or divided doses. Oral potassium chloride supplementation is important to prevent hypokalemia, which may predispose to digitalis toxicity.

Treatment of pulmonary edema

Patients with severe respiratory distress and pulmonary edema should be transferred to ICU where facilities for mechanical ventilatory support are available.

1. **Oxygen and diuretic therapy:** Inspired oxygen concentration is increased to 60-70% to correct hypoxemia and furosemide is given I.V. in a dose of 2 mg/kg/dose every 12 hours to reduce pulmonary congestion. Evaluation of response by monitoring of arterial oxygen saturation and measurement of arterial blood gases is essential.
2. **Continuous positive airway pressure (CPAP):** Persistent hypoxemia in spite of high oxygen and diuretic therapy is an indication of endotracheal intubation and continuous positive airway pressure. The mechanism by which CPAP improves oxygenation is not by pushing fluid out of alveoli but by increasing functional residual capacity and expanding fluid-filled alveoli. During weaning from CPAP, venous return increases and this requires a decrease of fluid administration, diuretic therapy or both.
3. **Mechanical ventilation:** In advanced cases complicated with respiratory failure (PaCO_2 above 60 mm Hg) in spite of the above measures, mechanical ventilatory support is indicated (see therapeutic interventions).

Treatment of cardiogenic shock

1. **Inotropic drug support:** Digoxin is not a suitable inotropic drug in cardiogenic shock because of its narrow therapeutic range and the possibly associated electrolyte disturbances and renal impairment in shock states. Inotropic catecholamines (dopamine and/or dobutamine) are suitable because of their immediate effect and dose-dependent response (for details of therapy, see shock).
2. **Vasodilator drug support:** In extremely severe cases not responding to inotropic catecholamine continuous infusion, the use of vasodilators as sodium nitroprusside can be useful to reduce afterload and to improve myocardial performance.

Specific treatment

Treatment of the causative disease is an integral part of successful therapy. Myocarditis, endocarditis, rheumatic activity, acute renal failure, hypertensive crisis or paroxysmal atrial tachycardia should be treated with the appropriate lines of therapy.

9 Chapter

Circulatory Failure (Shock)

Clinical grading of shock

Grade I (Early shock = peripheral hypoperfusion)

Tachycardia and poor peripheral perfusion

Grade II (Established shock = arterial hypotension)

Tachycardia, poor peripheral perfusion and hypotension

Grade III (Advanced shock = vital organ hypoperfusion)

Multiple organ system failure (MOSF)

Grade IV (Irreversible shock = irreversible cellular damage)

Refractory metabolic acidosis

Causes of shock

S: Septic shock

Primary septicemia (due to fulminant sepsis)

Secondary septicemia (due to serious focal infection)

H: Hypovolemic shock

Severe dehydration (severe diarrhea, severe vomiting, diabetic ketoacidosis)

Severe hemorrhage (external or internal and traumatic or spontaneous)

O: Obstructive shock

Tension pneumothorax or hemothorax

Cardiac tamponade (due to pericardial effusion or hemopericardium)

C: Cardiogenic shock

Severe acute heart failure or advanced shock (myocardial ischemia)

Late septic shock (due to toxic myocarditis)

K: Kinetic or Distributive shock

Anaphylactic shock (due to drugs, foods, insect stings, serums, immunoglobulins)

Neurogenic shock (head trauma)

Management of shock

Cardiovascular support

Oxygen therapy (to correct hypoxemia)

Preload augmentation (Ringer's lactate: 20 ml/kg, I.V. over 10-15 minutes)

Contractility augmentation (I.V. infusion of dopamine, dobutamine or both)

Afterload reduction (I.V. infusion of nitroprusside)

Treatment of arrhythmias (arrhythmias are common with advanced shock)

Multisystem support

Treatment of multiple organ system failure (MOSF)

Specific treatment

According to the causative disease

Shock or circulatory failure is a serious life-threatening condition characterized by hypoperfusion of tissues. This hypoperfusion can result from decreased blood volume (hypovolemic shock), decreased myocardial contractility (cardiogenic shock), obstruction to blood flow (obstructive shock), venular and arterial dilatation (distributive shock) or combination of factors (septic shock). Other uncommon causes of shock include acute suprarrenal failure, acute pancreatitis and pulmonary embolism.

PATHOPHYSIOLOGY

Hypoperfusion of tissues is serious as it leads to tissue ischemia (hypoxia and substrate deficiency) and tissue damage. The pathophysiological changes in shock passes into 3 progressive stages (compensated, decompensated and irreversible).

- o During the early **compensated stage**, there is excess catecholamine release to prevent the fall in blood pressure.
- o During the **decompensated stage**, compensatory mechanisms fail and hypotension occurs. Hypoperfusion of vital organs (kidneys, lungs, heart, brain) occurs leading to multiple organ system failure (MOSF). The injury to vital organs has 2 mechanisms:
 1. Initial ischemic phase caused by the hypoperfusion, and
 2. Late reperfusion phase that occurs following successful restoration of circulation. Reperfusion injury is caused by the release of several harmful mediators from the endothelium, endotoxins and cellular reactions (platelets, leukocytes).
- o During the **irreversible stage**, permanent cellular damage (of mitochondria and cell membrane) occurs secondary to persistent tissue hypoxia and anaerobic metabolism.

Pathophysiological stages of shock

Compensated stage

Excess catecholamine release to prevent hypotension.

Clinical manifestations (tachycardia, poor peripheral perfusion) are due catecholamine release.

Decompensated stage

Compensatory mechanisms fail and hypotension occurs.

Clinical manifestations are related to vital organ injury:

Initially: Hypoperfusion or ischemic injury (ischemic phase).

Lately: Reperfusion injury (reperfusion phase).

Irreversible stage

Permanent cellular damage.

Death occurs due to refractory acidosis, myocardial and brain ischemia.

DIAGNOSIS

Diagnosis of shock should include the stage and the cause of shock.

Clinical stages of shock

Although there is no sharp demarcation between the several events occurring in shock, it is clinically possible to divide shock into 4 stages with increasing severity. This

classification is practically useful as the clinical manifestations; outcome and therapeutic lines are different according to the stage.

1. **Early shock:** During this initial stage, clinical manifestations of shock are related to catecholamine release and include tachycardia and poor peripheral perfusion. Tachycardia aims to improve the tissue perfusion through increasing the cardiac output. Poor peripheral perfusion aims to increase perfusion of vital organs (brain, heart, lungs, kidneys) at the expense of nonvital organs (skin and extremities). This selective redistribution of blood is a physiologically useful mechanism to prevent hypotension. During this stage, clinical manifestations of shock are usually overshadowed by the clinical manifestations of the cause. High index of suspicion is important and shock should be suspected and expected in all conditions known to lead to shock (see below).

Signs of peripheral hypoperfusion

Cold extremities and increased core-peripheral temperature difference (more than 2°C).
Slow capillary refill over fingernails (refill in more than 5 seconds).
Skin mottling and peripheral cyanosis.

- **Core-peripheral temperature difference** can be assessed by the difference between rectal temperature (core) and skin temperature over toes (peripheral). A special skin probe and digital thermometer for this purpose is available. In normal conditions, the difference is less than 2°C.
 - **Capillary refill time** can be assessed by applying blanching pressure over a finger nail for 5 seconds. In normal conditions, capillary refill occurs in less than 3 seconds.
 - **In septic shock**, peripheral vasoconstriction is absent and on the contrary, peripheral perfusion is enhanced leading to "warm shock".
2. **Established shock:** With continued hypoperfusion and failure of compensatory mechanisms, hypotension occurs. The clinical triad of tachycardia, hypotension and poor peripheral perfusion becomes evident. Initially, systolic pressure decreases but eventually both systolic and diastolic pressure decrease. Early manifestations of hypoperfusion of vital organs start to appear especially metabolic acidosis (deep rapid respiration), renal hypoperfusion (oliguria or urine flow less than 1 ml/kg/hour) and brain hypoperfusion (irritability followed by drowsiness and confusion). Serial measurements of blood pressure are important and any observed fall in blood pressure should be treated vigorously before serious cellular damage occurs.
 3. **Advanced shock:** With continued hypotension, selective redistribution of blood occurs where perfusion increases to most vital organs (brain and heart) at the expense of less vital organs (kidneys, lungs and GIT). Manifestations of acute failure of different systems occur with a variable severity and different combinations. Even after successful correction of hypotension and restoration of normal perfusion, tissue damage of vital organs continues due to the release of different harmful mediators from endothelium, endotoxins and different cells (reperfusion injury).

4. **Irreversible (refractory) shock:** During this terminal stage, persistent tissue hypoxia and anaerobic metabolism will eventually lead to irreversible cellular damage (of mitochondria and cell membrane). Clinically, myocardial ischemia (serious arrhythmias) and brain ischemia (deep coma) are well evident. Metabolic acidosis is severe or profound and is refractory to therapy (pH is below 7.0 in spite of vigorous correction with sodium bicarbonate). Diagnosis of this stage is usually made retrospectively.

Manifestations of multiple organ system failure (MOSF)

Kidneys: Acute renal failure (oliguria, metabolic acidosis).

Lungs: Adult respiratory distress syndrome (ARDS).

GIT: Ischemia, stress ulcers, hemorrhage, ileus, gut translocation of bacteria.

Liver: Acute hepatic failure.

Blood: Disseminated intravascular coagulation (DIC), thrombocytopenia.

Metabolic: Metabolic acidosis (due to anaerobic metabolism), electrolyte disturbance.

Brain: Hypoxic ischemic encephalopathy (disturbed consciousness).

Heart: Myocardial ischemia, serious arrhythmias.

- **Respiratory distress** during this stage can be caused by severe metabolic acidosis, adult respiratory distress syndrome, endogenous infection (due to translocation of bacteria from the gut) or nosocomial pneumonia.

Cause of shock

Shock can be etiologically classified into 5 types. Although this classification is generally useful, it is important to realize the following facts:

- **Mixed shock:** More than one type of shock can coexist in the same patient. For instance, a child with traffic road accident (TRA) may suffer from hypovolemic shock (hemorrhage), neurogenic shock (head injury) and obstructive shock (hemothorax or hemopericardium). Similarly, the infant with severe gastroenteritis may develop hypovolemic shock (severe dehydration) and septic shock (septicemia).
- **Changing shock:** The mechanism of shock can be changing with time in the same patient. In septic shock, the early stage is distributive and the late stage is cardiogenic. Moreover, in any severe shock state and whatever the cause, septic shock may occur on top due to intestinal ischemia and translocation of bacteria from the gut to blood and various organs (gut barrier failure).
 1. **Septic shock:** It is a common and serious type of shock caused by gram, negative bacteria that release endotoxins (endotoxemic shock). It may also be caused by other organisms especially viruses and fungi. In the early stage, it is a distributive shock (due to vascular dilatation and relative hypovolemia) and in the late stage it becomes a cardiogenic shock (due to myocardial dysfunction or toxic myocarditis). Clinical manifestations of sepsis and shock can be divided into 5 stages with increasing severity (see below). It is important to recognize that the diagnosis of septic syndrome is a clinical diagnosis based on actual presence or

a high suspicion of infection. In addition, identification or isolation of the organism is not necessary for diagnosis (only 45% of patients have positive cultures).

Clinical progression of sepsis to septic shock and MOSF

I. Sepsis and Systemic inflammatory response syndrome (SIRS)

Clinical manifestations of infection.

Fever or hypothermia.

Tachycardia and tachypnea.

Bandemia (above 10%), leukocytosis or leukopenia, elevated ESR and CRP.

II. Severe sepsis

Clinical manifestations of sepsis plus one or more of the following 4:

Acute mental changes, oliguria, lactic acidosis or hypoxemia.

III. Early septic shock

Clinical manifestations of severe sepsis.

Hypotension or poor peripheral perfusion that responds rapidly to I.V. fluids.

Peripheral hypoperfusion is usually absent during this stage (warm shock).

IV. Late or refractory septic shock

Clinical manifestations of severe sepsis.

Hypotension or poor peripheral perfusion refractory to I.V. fluids (for more than 1 hour).

Peripheral hypoperfusion is marked during this stage (cold shock).

Inotropic drug support is necessary to improve myocardial contractility.

V. Multiple organ system failure (MOSF)

More than one of the following 5 (DIC, adult respiratory distress syndrome, acute renal failure, acute hepatic failure, acute CNS dysfunction).

Mortality rate is very high during this stage (50%).

2. **Hypovolemic shock:** It is the most common type of shock in children, which occurs due to intravascular volume loss (water, blood or plasma). Poor peripheral perfusion occurs early and hypotension appears in severe cases. Clinical diagnosis is not difficult as the manifestations of the causative disease are well evident (dehydration, hemorrhage, burn). Assessment of severity depends on the degree of dehydration (see metabolic emergencies), or plasma loss in burns (see serious injuries). It usually responds dramatically to volume expansion and specific replacement therapy (fluids, blood or plasma).
3. **Obstructive shock:** This type of shock occurs due to either obstruction of venous return (pneumothorax, cardiac tamponade, therapeutic procedures as mechanical ventilation or peritoneal dialysis) or obstruction of arterial flow (critical stenosis, critical aortic stenosis, critical coarctation). The condition should be suspected in any shock state not responding to volume expansion. Chest X-ray (pneumothorax) and echocardiography (cardiac tamponade) are essential for diagnosis.

4. **Cardiogenic shock:** It is a serious type of shock that occurs due to severe myocardial ischemia, severe acute congestive heart failure, late stage of septic shock or following cardiac surgery. Clinical diagnosis depends on proper evaluation and a high index of suspicion (see below). Invasive hemodynamic monitoring and vasopressor support (inotropic drug infusion) are necessary.

Clinical situations suggesting cardiogenic shock

Shock following cardiopulmonary resuscitation (due to myocardial ischemia).

Shock in patients with known congenital or acquired heart disease.

Shock in patients without history of cardiac disease but with cardiomegaly.

Septic shock not responding to I.V. fluid expansion (for more than 1 hour).

5. **Distributive shock:** It occurs due to vascular dilatation (venular or arterial), which leads to relative hypovolemia and decreased venous return. Early septic shock, anaphylactic shock and neurogenic shock are the classic three examples. In anaphylactic shock, prodromal symptoms of flushing, itching, facial swelling, urticaria, stridor or wheezing may precede shock and may be the only manifestations of anaphylaxis. All these types respond to volume expansion and specific therapy (antibiotics in septic shock and antihistamines and steroids in anaphylactic shock).

MANAGEMENT

The goals of therapy in shock states are to normalize tissue perfusion of vital organs and to support the failing systems until recovery occurs. These objectives can be achieved through monitoring, cardiovascular support, multisystem support and specific treatment of the causative disease.

Monitoring

As shock is unstable rapidly changing condition with time and therapy, frequent repeated assessment of several parameters are essential to follow the course of illness (improvement or deterioration) and to evaluate the response to therapy. In early stages of shock, simple clinical monitoring (heart rate, respiratory rate, peripheral perfusion, blood pressure, urine flow and level of consciousness) can be sufficient. In late stages or severe cases of shock (especially septic shock and cardiogenic shock), full clinical and laboratory monitoring are indicated including invasive hemodynamic measurements (central venous pressure, pulmonary artery pressure and cardiac output).

Monitoring in severe shock states**Clinical monitoring**

Heart rate and respiratory rate (continuous monitoring including ECG is preferable).
 Peripheral perfusion (skin temperature, core-toe temperature difference, capillary refill time).
 Arterial blood pressure (systolic, diastolic and mean arterial pressure).
 Urine output (normally, 2 - 3 ml/kg/hour. Oliguria is urine flow less than 1 ml/kg/hour).
 Level of consciousness (conscious, drowsy, confused, comatose).
 Arterial oxygen saturation by pulse oximeter (normal saturation is above 95%).
 (With very poor peripheral perfusion, the probe of pulse oximeter can be wrapped around the ear lobule, the nose or the penis).

Laboratory monitoring

Arterial blood gases (to detect hypoxemia and metabolic acidosis).
 Serum electrolyte (hypocalcemia and hypokalemia are common with bicarbonate therapy).
 Blood sugar with hemoglukotest (stress or exhaustion hypoglycemia are common).
 Hemoglobin and coagulation profile (Hb, platelet count, prothrombin time).
 Sepsis screen (complete blood count, ESR, CRP and blood culture).
 Renal function tests (blood urea and serum creatinine).

Radiological and imaging monitoring

Chest X-ray (to detect pneumothorax, lung pathology, cardiomegaly).
 Echocardiography (to evaluate cardiac function and to detect cardiac tamponade).
 Doppler echocardiography (for noninvasive measurement of cardiac output).

Invasive hemodynamic monitoring**Measured values**

Central venous pressure (CVP).
 Pulmonary artery pressure (PAP) and pulmonary capillary wedge pressure (PCWP).
 Cardiac output (CO).

Derived values

Cardiac index (CI) = $CO/BSA = 3 - 5 \text{ liters/minute/m}^2$.
 Systemic vascular resistance (SVR) = $80 (MAP - CVP)/CI = 800 - 1600 \text{ dyn-sec/cm}^5/\text{m}^2$.
 Pulmonary vascular resistance (PVR) = $80 (MPAP - PCWP)/CI = 80 - 240 \text{ dyn-sec/cm}^5/\text{m}^2$.

- **Central venous pressure (CVP)** is measured by a needle or catheter in a central vein (usually the femoral) connected to a calibrated tube filled with sterile saline (saline manometer). The level of blood in the tube corresponds to venous pressure in cm H₂O. Normal value is 1-5 cm H₂O. Low value occurs in hypovolemic shock and high value (above 7 - 10 cm H₂O) occurs in volume overload, cardiogenic shock, obstructive shock (tamponade, pneumothorax) and pulmonary hypertension.
- **Pulmonary artery pressure (PAP)** is measured by using the flow directed multi-lumen pulmonary artery catheter (Swan-Ganz catheter). Normal value is 25/10 mmHg with mean value of 16. Acute pulmonary hypertension (due to pulmonary vasoconstriction) occurs in severe septicemia, severe metabolic acidosis and shock lung. Pulmonary capillary wedge pressure (PCWP) is also measured to reflect the left atrial pressure. Normal value is about 8 mm Hg.

- **Cardiac output (CO)** is measured by using the pulmonary artery catheter and a thermodilution or dye dilution technique. From cardiac output, stroke volume (SV) can be derived and it equals $CO/\text{heart rate}$. It is also important to note that cardiac output equals the perfusion pressure/systemic vascular resistance or $CO = MAP - CVP/SVR$.
- **Cardiac index (CI)** is derived from cardiac output (CO) and body surface area (BSA) and it equals CO/BSA . Normal value is 3 - 5 liters/minute/m².
- **Systemic vascular resistance (SVR)** is derived from mean arterial pressure (MAP), central venous pressure (CVP) and cardiac index (CI). It equals $80 (MAP - CVP)/CI$. Normal value is 800-1600 dyn-sec/cm⁵/m². Mean arterial pressure is calculated from systolic pressure (SP) and diastolic pressure (DP) where $MAP = DP + 1/3 (SP - DP)$. In other words it equals the diastolic pressure plus one third of the difference between systolic and diastolic pressures.
- **Pulmonary vascular resistance (PVR)** is derived from mean pulmonary artery pressure (MPAP), pulmonary capillary wedge pressure (PCWP) and cardiac index (CI). It equals $80 (MPAP - PCWP)/CI$. Normal value is 80 - 240 dyn-sec/cm⁵/m².

Cardiovascular support

Proper cardiovascular support in shock states requires basic understanding of the hemodynamic changes that occur in different types of shock. Therefore, it is therapeutically useful to classify shock according to intravascular volume into 2 groups (hypovolemic and normovolemic/hypervolemic).

Hemodynamic classification of shock

Intravascular hypovolemia

Hypovolemic shock (true hypovolemia)

Decreased cardiac output, decreased CVP, markedly elevated SVR.

Treatment is by volume expansion and replacement therapy (fluids, blood, plasma).

Distributive shock (relative hypovolemia)

Increased cardiac output, decreased CVP, decreased SVR.

Treatment is by volume expansion and specific therapy (vasoconstrictors).

Intravascular normovolemia/hypervolemia

Caused by cardiogenic shock and obstructive shock.

Echocardiography is essential for diagnosis and differentiation.

Decreased cardiac output, normal or increased CVP, markedly elevated SVR.

Treatment is by careful volume expansion and inotropic drug infusion.

Relief of obstruction and afterload reducing agents may be considered.

With these hemodynamic considerations, cardiovascular support in shock states can include the following five steps:

1. **Oxygen therapy:** Oxygen is the first essential drug in shock and it aims to prevent myocardial hypoxia and serious arrhythmias, which can be fatal. A high oxygen concentration (near 100%) is given by an oxygen mask and the concentration can be gradually decreased over the next few hours. Endotracheal intubation and mechanical ventilation should be considered in case of marked distress.

2. Preload augmentation: Expansion of intravascular volume with volume expanders (crystalloids and colloids) is initially indicated in all types of shock to improve tissue perfusion.

- A **crystalloid** (Ringers lactate or saline) is initially given, I.V. in an amount of 20 ml/kg over 10 - 15 minutes. **The dose can be repeated once or even twice** in case of poor response (persistent poor peripheral perfusion and/or hypotension).
- A **colloid** (albumin, plasma) may also be given in an amount of 10 ml/kg, I.V. over a period of 15 minutes. It has the advantages of maintaining oncotic pressure and less tendency to leak into the interstitial spaces.
- **Whole blood transfusion** (10 - 20 ml/kg) can also be given in hemorrhagic shock or when hemoglobin level is very low.
- Failure of response to 50 - 70 ml/kg of volume expanders over the first 1 - 2 hours should suggest cardiogenic shock or obstructive shock. Chest X-ray should be immediately done to exclude tension pneumothorax and echocardiography is urgently indicated to assess cardiac function and to detect obstructive lesions especially those necessitating urgent intervention as cardiac tamponade. Invasive hemodynamic monitoring should also be considered to guide therapy. According to central venous pressure (CVP), poor response to volume expansion can be classified into two groups (see below). When facilities for urgent echocardiography and invasive hemodynamic monitoring are not available, the condition should be considered as a cardiogenic shock and inotropic drug infusion (dopamine and/or dobutamine) should be started.

Causes of failure of response to volume expansion

With low central venous pressure (hypovolemia)

- Continued unrecognized fluid loss (capillary leak syndrome).
- Continued unrecognized blood loss (internal hemorrhage).

With high central venous pressure (above 7 - 10 cm H₂O)

- Volume overload (due to renal failure or excess I.V. fluids).
- Cardiogenic shock (impaired contractility).
- Obstructive shock due to pneumothorax or cardiac tamponade (impaired preload).
- Pulmonary hypertension (impaired right ventricular out-flow).

3. Contractility augmentation: Continuous **I.V. infusion of inotropic** catecholamines is used to improve myocardial contractility and cardiac output in patients with cardiogenic shock and late septic shock not responding to volume expansion. These drugs have the advantages of immediate effect and dose-dependent response. **Dopamine** is the most commonly used initial drug and it is given in a dose of 5 - 20 mcg/kg/minute. **Dobutamine** can be added in a dose of 5 - 20 mcg/kg/minute when dopamine alone is not effective. As dobutamine has a less prominent chronotropic effect, it is the preferable initial drug when marked tachycardia is present. Adrenaline may be used in extremely severe or desperate cases in a dose of 0.05-1.0 mcg/kg/minute. As adrenaline causes marked peripheral vasoconstriction and reduction in renal blood flow, a vasodilator drug (as nitroprusside) should be

used simultaneously to counteract its undesirable effects. *Isoproterenol* (0.05-2 mcg/kg/minute) is only used when severe bradycardia is present and when pulmonary vasodilatation is required. As inotropic catecholamines are serious drugs, their use should be limited to ICU where facilities for continuous monitoring are available. Other important precautions in use of inotropic catecholamines are; (1) as rapid administration could be fatal, the I.V. line should never be used for other drugs and should never be flushed, (2) The infusion should never be interrupted or stopped suddenly, but gradual withdrawal should be the rule, (3) an infusion pump should be used for proper and accurate adjustment of dosage, and (4) invasive hemodynamic monitoring, if available, can greatly guide therapy as these drugs have a different hemodynamic effects.

Inotropic drug support in cardiogenic shock

Drug	Trade name	Dose (mcg/kg/min.)	Effects
Dopamine	Intropin amp. (200 mg/5 ml)	Low (0.5 - 4) Medium (5 - 10) High (11 - 20)	Renal vasodilator Inotropic Peripheral vasoconstrictor
Dobutamine	Dobutrex vial. (250 mg/10 ml)	2 - 20	Inotropic Peripheral vasodilator Pulmonary vasodilator
Adrenaline	Adrenaline amp. (1 mg/ml)	0.05 - 1.0	Inotropic Peripheral vasoconstrictor Pulmonary vasoconstrictor
Isoproterenol	Isuprel amp. (1 mg/5 ml)	0.05 - 2.0	Inotropic, bronchodilator Peripheral vasodilator Pulmonary vasodilator

- **For dopamine or dobutamine**, the method for dilution and infusion rate is:
Add (6 mg × body weight) to 100 ml glucose 5%.
In this solution, each 1 ml/hour equals 1 mcg/kg/minute.
- **For adrenaline or isoproterenol**, the method for dilution and infusion rate is:
Add (0.6 mg × body weight) to 100 ml glucose 5%.
In this solution, each 1 ml/hour equals 0.1 mcg/kg/minute.

4. Afterload reduction: The use of afterload reducing agents (vasodilators) should be considered to improve myocardial performance in patients with severe cardiogenic shock not adequately responding to inotropic drug support. These drugs are also indicated when adrenaline is used as inotropic drug (see above).

- Reduction of *systemic vascular resistance and left ventricular afterload* can be achieved by nitroprusside or nitroglycerine. Both drugs act through generation of nitric oxide (NO). **Sodium nitroprusside** is given in a dose of 0.5 - 10 mcg/kg/minute. It is an arterial vasodilator more than venous vasodilator. Nitroglycerin is given in a dose of 1-20 mcg/kg/minute. It is a more potent venodilator and pulmonary vasodilator than arterial vasodilator. Amrinone is a new effective drug, which can be used in a dose of 1-20 mcg/kg/minute. It is a phosphodiesterase inhibitor, which has both inotropic effect and afterload reducing effect.

- Reduction of *pulmonary vascular resistance and right ventricular afterload* can also be achieved by nitroprusside or nitroglycerin. Other drugs with pulmonary vasodilating effect include *dobutamine, isoproterenol, tolazoline* and *prostaglandin I₂ (prostacyclin)*. As all these drugs have also a potent peripheral vasodilator effect, close monitoring and volume expansion are necessary. It is important to remember that treatment of acute pulmonary hypertension includes other important measures as hyperoxygenation, hyperventilation, sedation and muscle relaxation (see acute pulmonary hypertension).

Afterload reducing agents in severe cardiogenic shock

Drug	Trade name	Dose (mcg/kg/min)	Effects
Nitroprusside	Nipride vial. (50 mg/2 ml)	0.5 - 10	Arterial dilatation (+ + +) Venous dilatation (+)
Nitroglycerin	Tridil amp. (50 mg/10 ml)	1 - 20	Venous dilatation (+ + +) Arterial dilatation (+)
Amrinone	Incor amp. (100 mg/20 ml)	1 - 20	Vasodilator Inotropic

- As sodium nitroprusside is rapidly inactivated by light (photochemical degradation), the drip bottle and the tubing system should be covered with aluminium paper (included with the vial).

5. Treatment of arrhythmias: Initial treatment of any acute arrhythmias should include correction of hypoxia, acidosis and electrolyte disturbance (hypocalcemia, hypomagnesemia, hypokalemia or hyperkalemia). Antiarrhythmic drugs for bradyrhythmias include atropine and isoproterenol. Supraventricular tachyarrhythmias is treated with adenosine, verapamil or propranolol. Lidocaine is the main drug for ventricular tachyarrhythmias (see cardiac arrhythmias).

Summary of cardiovascular support in shock states

- Oxygen therapy**
Give oxygen (100 %) with an oxygen mask.
Reduce concentration over the next few hours.
- Preload augmentation (volume expansion)**
Give Ringers lactate or saline (20 ml/kg, I.V. over 10- 15 minutes).
Consider albumin or plasma transfusion (10 ml/kg over 15 minutes).
Urgent chest X-ray and echocardiography if no response to above measures.
- Contractility augmentation (inotropic drug support)**
Indicated in poor response to volume expansion.
Give dopamine I.V. infusion (5 - 20 mcg/kg/minute).
Add dobutamine (5 - 20 mcg/kg/minutes) when the response is inadequate.
Consider adrenaline (0.05 - 1.0 mcg/kg/minute) in extremely severe cases.
Consider invasive hemodynamic monitoring.
- Afterload reduction (vasodilator drugs)**
Indicated in poor response to inotropic drug support.
Give sodium nitroprusside I.V. infusion (0.5 - 10 mcg/kg/minute).
Consider pulmonary vasodilator drugs.
- Treatment of arrhythmias**
Correct hypoxia, acidosis and electrolyte disturbances.
Give the appropriate antiarrhythmic drug.

Multisystem support

In advanced shock states, both hypoperfusion and reperfusion injuries result in multisystem deterioration and development of multiple organ system failure (MOSF). Simultaneous support of the failing systems should accompany the cardiovascular support because in many patients, and in spite of successful cardiovascular support, death occurs due to multiple system failure.

Respiratory, renal, metabolic, gastrointestinal and hematological abnormalities should be early identified and treated. It is important to re-emphasize that ensuring a patent airway and adequate oxygenation is always the first step in all emergencies. It is also important to remember that the threshold for intubation and mechanical ventilation in shock states should be low. Respiratory failure in shock is multifactorial and may occur due to respiratory muscle fatigue, cardiogenic pulmonary edema, adult respiratory distress syndrome, pulmonary hypertension and nosocomial pneumonia.

Multisystem support in MOSF**Respiratory support**

Early oxygen therapy in all cases to prevent or delay respiratory fatigue.
Endotracheal intubation and CPAP for pulmonary edema.
Endotracheal intubation and CPAP or mechanical ventilation for ARDS.
Hyperoxygenation and hyperventilation for acute pulmonary hypertension.

Renal support

Keep urine output above 1 ml/kg/hour.
Give volume expanders, diuretics and low dose dopamine in oliguria.
Consider peritoneal dialysis in severe cases.

Metabolic support

Correct hypothermia and hyperthermia (both increase metabolic demands).
Correct metabolic acidosis with sodium bicarbonate.
Correct electrolyte disturbances (hypocalcemia, hypomagnesemia or hyperkalemia).
Correct hypoglycemia or hyperglycemia.

Gastrointestinal support

Antacids, cimetidine and cold saline wash for gastric stress ulcers.
Intestinal decontamination may be considered to prevent gut translocation of bacteria.
Rest of GIT in ileus (give maintenance I.V. fluids, parenteral nutrition).

Hematological support

Correct coagulopathies with vitamin K, fresh frozen plasma and platelets.
Consider heparinization if peripheral gangrene occurs.

Specific treatment

Early specific management of the underlying cause of shock will often delay further progression or deterioration requiring more aggressive therapy.

- In sepsis or septic shock, early combined parenteral antibiotic therapy is essential. A combination of ampicillin (100 mg/kg/day, I.V.) and a third generation cephalosporin as cefotaxime (100 - 200 mg/kg/day, I.V.) is a reasonable initial therapy. In neonates, ampicillin and an aminoglycoside as amikacin (15 mg/kg/I.V.) is the

standard initial therapy. Therapy can be changed according to the clinical response and the results of culture-sensitivity studies.

- **In hypovolemic shock**, specific replacement therapy is essential. In dehydration, deficit I.V. fluid therapy and replacement of ongoing losses are important. In hemorrhagic shock, stopping hemorrhage and replacement whole blood transfusion are mandatory (see hematological emergencies). In burns, plasma transfusion and several other measures are required (see serious injuries).
- **In obstructive shock**, management depends on the type of obstruction:
 - a. Venous obstruction:*** In conditions impairing venous return as pneumothorax and cardiac tamponade, early surgical intervention (thoracocentesis or pericardiocentesis) is essential to relieve obstruction.
 - b. Arterial obstruction:*** In patients with critical obstructive lesions to pulmonary blood flow (critical pulmonary stenosis) or systemic blood flow (critical aortic stenosis or critical coarctation), **prostaglandin E1 continuous infusion** is used to reopen and maintain the patency of ductus arteriosus (see duct-dependent CHD).
- **In cardiogenic shock**, specific **treatment of the underlying cause**, if available, should be instituted. For instance, arrhythmias should be promptly corrected and rheumatic carditis should receive anti-inflammatory therapy including corticosteroids.
- **In anaphylactic shock**, early drug therapy with **anti-allergic drugs is important**. **Adrenaline** is given **subcutaneously** or **preferably I.V.** in a dose of 0.01 mg/kg. The dose can be repeated after 5 - 10 minutes if the response is inadequate. Alternatively, it can be given through the endotracheal tube in a dose of 0.1 mg/kg (10 times the I.V. dose). **Hydrocortisone** is also given in a dose of 10 mg/kg, I.V. to prevent further release of histamine. **An antihistamine (see below) is also given I.V.** to prevent histamine from reaching its sites of action. Other measures include salbutamol nebulization in cases associated with bronchospasm.

Parenteral antihistamines

Drug	Trade name	Dose
Chlorpheniramine	Pirafene amp. (5 mg/ml).	0.2 mg/kg, I.V.
Pheniramine	Avil amp. (50 mg/2 ml).	1.0 mg/kg, I.V.
Clemastine	Tavegyl amp. (2 mg/2 ml).	0.04 mg/kg, I.V.

10

Chapter

Cardiac Arrhythmias

Diagnosis

Tachyrrhythmias

Sinus tachycardia
Supraventricular tachycardia
Ventricular tachycardia

Bradyrrhythmias

Sinus bradycardia
AV block (heart block)
Sick sinus syndrome

Cardiac arrest rhythms

Asystole
Electromechanical dissociation
Ventricular fibrillation

Management

Supraventricular tachycardia

Maneuvers to increase vagal tone
Drugs: Adenosine, verapamil, propranolol
Synchronized DC shock

Ventricular tachycardia

Treatment of hypoxia, shock, acidosis
Drugs: Lidocaine, phenytoin
Non-synchronized DC shock

Bradycardia

Treatment of hypoxia, shock, acidosis
Drugs: Adrenaline, atropine, isoproterenol
Consider cardiac pacing (pacemaking)

Abnormalities in the rate and rhythm of the heart can be physiological or pathological, acute or chronic and benign or life-threatening. Acute cardiac arrhythmias are serious life-threatening conditions, which can progress to acute congestive heart failure, cardiogenic shock or cardiac arrest.

DIAGNOSIS

Diagnosis of cardiac arrhythmias should include three aspects:

- a. **Recognition of the arrhythmia:** Cardiac arrhythmias are considered when the heart rate is too fast or too slow beyond the normal physiological range. Accurate diagnosis necessitates ECG tracing on a cardiac monitor (lead II) or preferably by 12 lead ECG. It is important to note that the width of QRS complexes is an important differentiating point between supraventricular and ventricular arrhythmias. Narrow QRS complexes occur with supraventricular arrhythmias while wide QRS complexes occur with ventricular arrhythmias. In case of cardiac arrest (no detectable heart beats or pulse), ECG can differentiate between the three cardiac arrest rhythms.
- b. **Identification of the precipitating factors:** Although some arrhythmias as paroxysmal supraventricular tachycardia occur suddenly without an evident cause, in most other arrhythmias a precipitating cause can be identified. Shock, hypoxia, metabolic acidosis and severe electrolyte disturbances are the most serious precipitating factors of severe bradycardia or ventricular tachycardia. These two serious arrhythmias can easily progress to cardiac arrest.

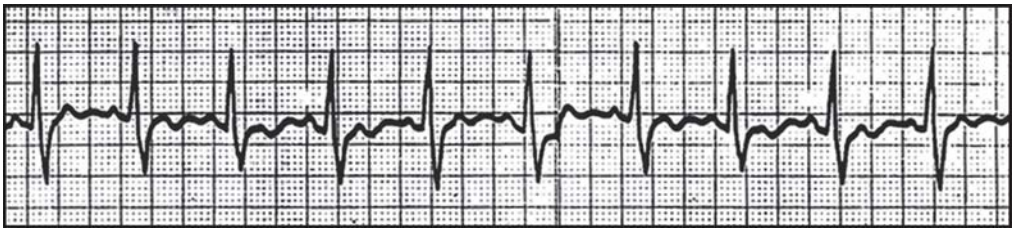
- c. **Physiological effect:** Mild to moderate arrhythmias can be well tolerated by children but severe cases can progress to heart failure, cardiogenic shock or cardiac arrest.

Tachyrrhythmias

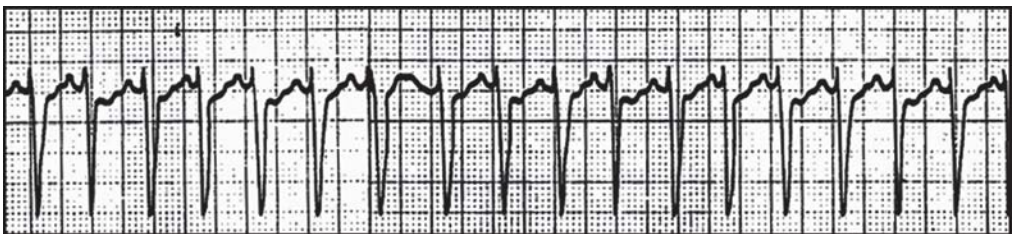
These disorders are characterized by rapid heart rate due to rapid discharge from SA node, supraventricular or ventricular ectopic foci.

1. **Sinus tachycardia:** It is the commonest disorder, which occurs due to rapid discharge from the sinoatrial node. The condition can be physiological (anxiety, exercise, crying, pain), pathological (fever, hypoxia, heart failure, shock, cardiac tamponade, anemia) or following drug therapy (adrenaline, atropine, theophylline).
 - Clinically, tachycardia disproportionate to the age is the main finding. Heart rate is usually below 220/minute. Clinical features of the cause are usually evident.
 - ECG reveals rapid heart rate with normal P wave and normal QRS complex.
 - As the condition represents a physiological compensatory mechanism, treatment should be directed to the cause and not for slowing the heart rate.
2. **Supraventricular tachycardias:** In these conditions, the rapid heart rate is originating from an abnormal mechanism proximal to the bifurcation of the bundle of His. Paroxysmal supraventricular tachycardia is the most common abnormality. Atrial flutter is rare.
 - In paroxysmal supraventricular tachycardia, the paroxysm (or the attack) occurs suddenly without an evident cause and usually at rest. The heart rate is usually above 220/minute, and often up to 300/minute in an infant. Short attacks for minutes or hours are well tolerated by most children but prolonged or exceptionally severe attacks can progress to acute congestive heart failure or even to cardiogenic shock. The attack as it begins suddenly also terminates suddenly.
 - ECG reveals very rapid heart rate (220 - 300/minute) with normal P-wave, normal AV conduction and normal QRS complex. In atrial flutter, a degree of AV block (2:1 or 3:1) is present and ECG shows a saw tooth P-wave, AV block and one QRS for each 2-3 P-waves.
 - As the condition is life-threatening, immediate treatment is indicated. Maneuvers to increase vagal tone should be tried first as it may successfully terminate the attack. Drugs are indicated in severe cases and when simple maneuvers are ineffective.
3. **Ventricular tachycardia:** In this serious arrhythmia, the rapid heart rate is originating from an abnormal mechanism in the ventricles.
 - Clinically, the heart rate ranges between 120 - 250/minute. The condition may occur with myocarditis, cardiomyopathy or digitalis toxicity. Shock, hypoxia, metabolic acidosis and electrolyte disturbances are important precipitating factors. If untreated or persistent, ventricular tachycardia can progress to fatal ventricular fibrillation.
 - ECG shows rapid wide QRS complexes not preceded by P-waves. Capture or fusion beats, if present, are diagnostic.
 - As the condition is very serious, immediate treatment is indicated.

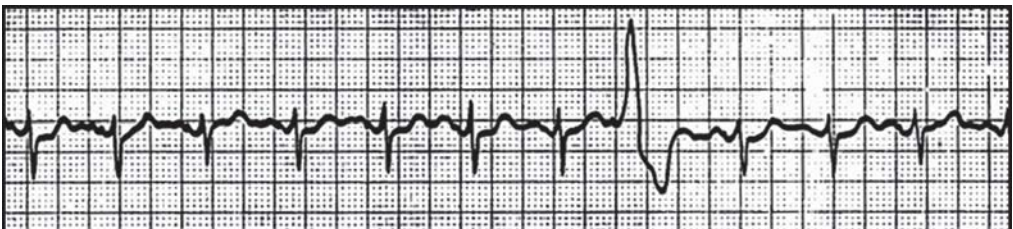
Sinus rhythm



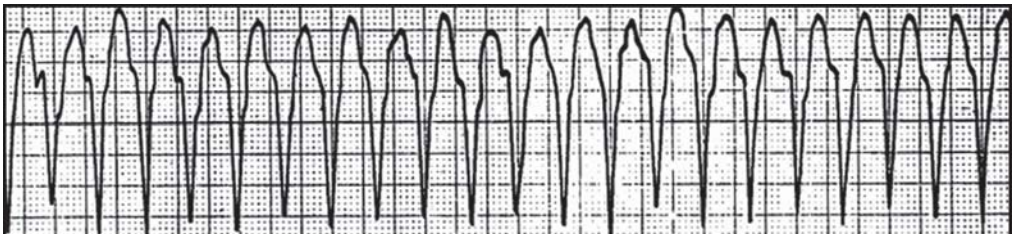
Supraventricular tachycardia



Ventricular extrasystole



Ventricular tachycardia



Ventricular fibrillation

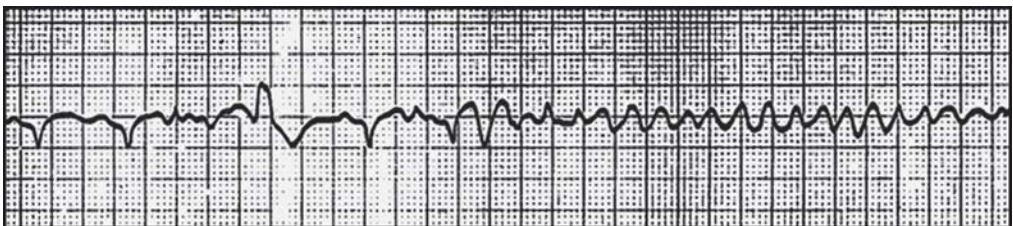


Fig. 10.1

Bradyrhythmias

These disorders are characterized by a slow heart rate due to slow discharge from SA node, AV block or other disorders of conduction. For diagnosis of bradycardia, the heart rate should be below the normal lower limit for age (below 100/minute in infants, 80/minute in young children and 60/minute in old children). During sleep, these lower limits are slightly lower.

Bradycardia is serious life-threatening condition, which may progress to cardiac arrest (asystole).

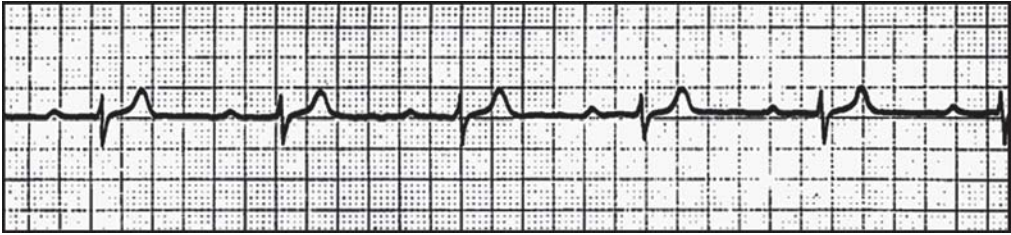
1. Sinus bradycardia: This condition is characterized by a slow discharge from the SA node leading to a slow heart rate. Acute causes include syncope, abdominal distension, increased intracranial pressure, stressful procedures (endotracheal intubation, suctioning, vigorous chest physiotherapy), cardiac surgery and drug therapy (digoxin, verapamil, propranolol). Shock, hypoxia and severe metabolic acidosis are important contributing factors.

- Clinically, slow regular (or irregular) heart rate is the main finding. In severe cases, the condition can rapidly progress to asystole. The heart rate characteristically increases with exercise (or crying), which differentiates the condition from AV block.
- ECG reveals slow heart rate with normal P, P-R interval and QRS complex.
- As the condition is life-threatening, immediate treatment is indicated.

2. Atrioventricular block (AV block or heart block): This arrhythmia can be congenital or acquired and it occurs following digitalis toxicity or cardiac surgery. Conduction block or delay at the atrioventricular level can be divided into 3 degrees:

- a. First degree AV block:** It is characterized by a prolonged P-R interval. The rhythm is regular and all impulses are conducted.
- b. Second degree AV block:** It is characterized by failure of conduction of some, but not all, atrial impulses to the ventricles. It is divided into 2 types.
 - i. Mobitz type I (Wenckebach phenomenon):* P-R interval becomes progressively longer until an atrial impulse is not conducted and a dropped beat occurs. This may occur over two, three, four or even five beats before non-conduction happens. The conduction delay occurs at the level of AV node.
 - ii. Mobitz type II:* It is characterized by intermittent irregular sudden dropping of beats not preceded by progressive P-R prolongation. It is more serious than type I because it frequently progresses to complete AV block. The level of conduction blockade is at the Bundle of His.
- c. Third degree AV block (complete heart block):** No impulses from atria reach the ventricles and complete atrioventricular dissociation occurs (no constant relation between P-waves and the slow wide QRS complexes). Complete heart block can be congenital or acquired. The prognosis of the congenital form is usually good. Digitalis toxicity is the most common cause of acquired cases.

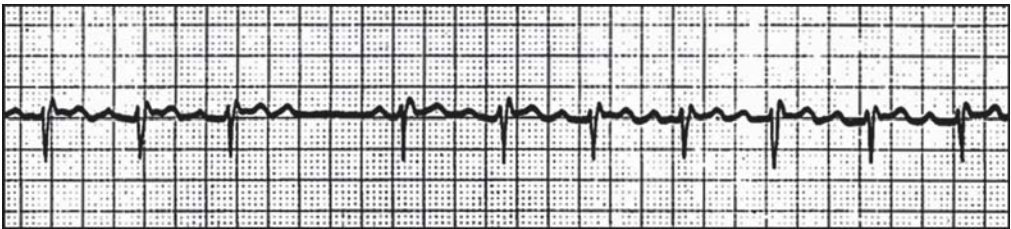
First degree AV block



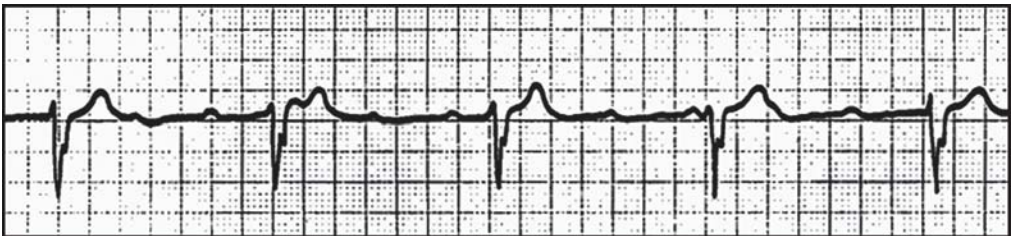
Second degree AV block (Mobitz type I)



Second degree AV block (Mobitz type II)



Third degree AV block (Complete heart block)



Asystole

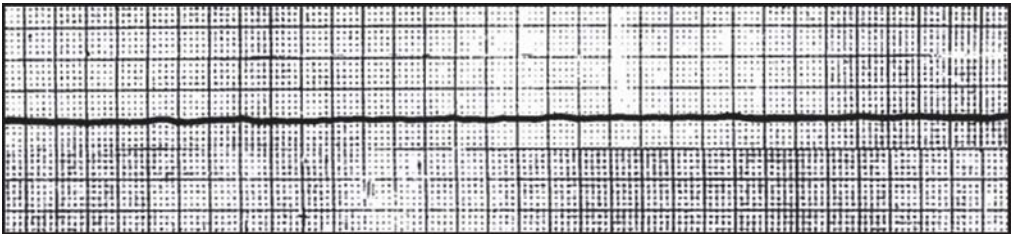


Fig. 10.2

3. **Sick sinus syndrome:** This arrhythmia mostly occurs following cardiac surgery but may also occur with myocarditis, myocardial ischemia or cardiomyopathy. It is characterized by periods of profound unresponsive sinus bradycardia with or without escape rhythms. These escape rhythms may give rise to periods of tachyarrhythmia, and hence, the name "bradycardia-tachycardia syndrome". In symptomatic patients, drug therapy or ventricular pacemaker is necessary.

Cardiac arrest rhythm

In case of cardiac arrest, immediate resuscitative measures should be done to restore the normal cardiac rhythm. ECG can differentiate between 3 cardiac arrest rhythms

1. **Asystole:** It is by far the most common arrest rhythm in children because the response of the young heart to severe hypoxia and acidosis is progressive bradycardia leading to asystole. The ECG appearance is an almost straight line (flat ECG).
2. **Electromechanical dissociation:** It is the absence of palpable pulse despite the presence of recognizable complexes on the ECG monitor. The most common cause in children is advanced shock, which makes the pulse very weak and difficult to feel. Other causes include electrolyte disturbance, tension pneumothorax and cardiac tamponade.
3. **Ventricular fibrillation:** This arrhythmia is uncommon in children but it may occur in those recovering from hypothermia and those with primary cardiac disease. It may follow ventricular tachycardia or occur suddenly following severe hypoxia, advanced shock or severe acid-base and electrolyte disturbance. The ECG shows complete disorganization with absent QRS complexes.

When immediate ECG is not available, the patient should be considered as having asystole (the most common) and should be managed as such.

MANAGEMENT

Management of cardiac arrhythmias depends on the type and on the physiological effect (stable or with congestive heart failure, cardiogenic shock or cardiac arrest). Continuous monitoring of the heart rate and ECG is essential and frequent measurement of blood pressure, respiratory rate and arterial oxygen saturation is important. Immediate I.V. line should be established.

Supraventricular tachycardia (SVT)

After adequate oxygenation, treatment of SVT includes the following:

1. **Maneuvers to increase vagal tone:** Increased vagal tone may interrupt electrical depolarization caused by irregular circus movements and is frequently successful to abort the attack and to convert SVT to normal sinus rhythm. It should be remembered that these techniques could occasionally lead to profound bradycardia or even asystole due to excessive vagal stimulation. Therefore, one should be ready to treat these arrhythmias if they happen.
 - a. **One-sided carotid sinus massage:** This simple technique can be used in all ages including infants.

2. **Drug therapy:** Lidocaine is the drug of choice for frequent premature ventricular contractions (PVCs) and ventricular tachycardia. It is given initially as I.V. bolus (1-2 mg/kg) followed by continuous infusion (30-50 mcg/kg/minute). The available preparation is Lidocaine vial (1 gm/50 ml). Phenytoin (3-5 mg/kg, I.V. over 5 minutes) is an alternative to lidocaine and is considered the drug of choice for digoxin-induced arrhythmias. The dose can be repeated every 10 minutes, if necessary, up to a total loading dose of 20 mg/kg. The available preparation is Epanutin amp. (250 mg/5 ml). After initial control with either drug, an oral maintenance therapy can be made with procainamide (50 mg/kg/day) or quinidine (30 mg/kg/day) when the recurrence risk is considerable.
3. **Non-synchronized DC shock:** In children presenting with VT and shock, non-synchronized DC shock is the therapy of choice. A dose of 1-4 Joules/kg is required and may be repeated until sinus rhythm occurs. This therapy is followed by a bolus and subsequent infusion of lidocaine.

Bradycardia

1. **Treatment of precipitating factors:** In pediatric emergency medicine, bradycardia is usually a preterminal finding in patients with severe respiratory failure or circulatory failure (shock). Therefore, urgent correction of hypoxia (oxygen, manual ventilation) and shock (volume expanders, inotropic drug support) should be made before any drug therapy. Similarly, stressful procedures (chest physiotherapy, suctioning) and responsible drugs (as digoxin) should be discontinued.
2. **Drug therapy:** When above measures are ineffective, drug therapy is indicated. Atropine (0.01 mg/kg, I.V.) is the first-line of choice and is usually effective in increasing the heart rate by its vagolytic effect. Adrenaline is indicated when atropine is not effective especially in neonates and in bradycardia due to heart block. It is given as a bolus dose (0.01 mg/kg, I.V.) followed by continuous infusion (0.1-1.0 mcg/kg/minute). Isoproterenol continuous infusion (0.1-1.0 mcg/kg/minute) may also be considered in severe A-V block not responding to atropine.
3. **Cardiac pacing:** Temporary or permanent implantation of a cardiac pacemaker is indicated in severe symptomatic bradycardia not responding to drug therapy. Persistent sinus tachycardia, congenital or surgically induced heart block and sick sinus syndrome are the main indications. Temporary pacing can be made by different techniques (transcutaneous pacing, transthoracic pacing, transesophageal pacing or transvenous insertion of a pacing catheter).

Cardiac arrest

In case of cardiac arrest, urgent cardiopulmonary resuscitation should be made. This includes basic life support (ABC), advanced life support (DEF) and prolonged life support (GHI). Training and experience are crucial for successful resuscitation (see cardiopulmonary resuscitation).

11

Chapter

Cardiac Tamponade

Diagnosis

Clinical diagnosis
Echocardiography

Management

Needle pericardiocentesis
Medical treatment

Cardiac tamponade (cardiac compression) occurs due to accumulated pericardial effusion or accumulated blood in the pericardiac sac. It is a serious life-threatening condition as it impairs venous return (cardiac filling) and leads to obstructive shock.

Accumulated pericardial effusion occurs with severe bacterial (purulent) pericarditis and the illness usually follows other bacterial infections as pneumonia or osteomyelitis. Hemopericardium is observed with severe chest trauma or following cardiac surgery.

DIAGNOSIS

The diagnosis of cardiac tamponade can be made clinically and confirmed by echocardiography.

Clinical diagnosis

With pericardial effusion due to purulent pericarditis, the onset of illness is acute with high fever, chest pain, dyspnea and cough. The course is fulminant and a considerable effusion rapidly accumulates leading to acute cardiac tamponade.

In case of hemopericardium, a history of chest trauma or cardiac surgery is well evident. Anemia due to acute blood loss (external or internal) may be severe. Acute cardiac tamponade occurs as more blood accumulates in the pericardiac sac.

Clinical manifestations of acute cardiac tamponade

Tachycardia with distant muffled heart sounds.
Enlarged heart with quiet precordium (dullness outside the apex).
Systemic congestion (distended neck veins, hepatomegaly).
Pulsus paradoxus (inspiratory lowering of blood pressure greater than 20 mm Hg).
With obstructive shock, hypotension and poor peripheral perfusion occurs.

- **Pulsus paradoxus** is an exaggeration of the normal reduction of systolic blood pressure during inspiration. Normally, inspiratory lowering of 5 mm Hg is observed. Values between 10 - 20 mm Hg is equivocal and value above 20 mm Hg is diagnostic.

Measurement of pulsus paradoxus with sphygmomanometer is made by observing the difference between 2 systolic pressures. The first pressure is the pressure with the first korotkoff sound heard intermittently (varying with respiration), while the second pressure is the pressure with the first korotkoff sound heard continuously. Pulsus paradoxus is also observed in asthma and in mechanically ventilated patients.

Echocardiography

With clinical diagnosis or even with clinical suspicion, urgent echocardiography is indicated to confirm the diagnosis and to assess the amount of accumulated effusion or blood. It is also useful to evaluate the progress of illness and to evaluate the efficacy of therapeutic intervention especially pericardiocentesis.

MANAGEMENT

Patients with acute cardiac tamponade should be transferred to ICU where facilities for continuous monitoring of the heart rate and ECO are available. Repeated measurement of blood pressure and assessment of peripheral perfusion are important for diagnosis of shock. Management includes the following aspects.

Needle pericardiocentesis

Needle pericardiocentesis (closed pericardial aspiration) is a lifesaving procedure in patients with cardiac tamponade. As the technique is risky, it is better to be done by a cardiac surgeon, and ECG monitoring throughout the technique is essential (ST segment changes or widened QRS indicates ventricular injury by the needle). A 20 ml syringe attached to 16 or 18-gauge needle is used. A skin puncture is made 1-2 cm below and to the left of the xiphoid junction at 45° angle, and then the needle is advanced towards the tip of the left scapula while aspirating all the time. Once fluid is withdrawn, aspiration should be made as much as possible. The needle is then removed leaving the cannula in the pericardiac sac as repeated aspiration may be needed. With pericardial effusion, a sample should be sent for culture and sensitivity studies.

Medical treatment

Oxygen should be given in a high concentration to prevent tissue hypoxia. Volume expanders (20 ml/kg of Ringers lactate or normal saline, I.V. over 10 - 15 minutes) should be urgently infused in shocked patients. With pericardial effusion, prolonged combined parenteral antibiotic therapy is indicated for weeks. An initial therapy with 3 drugs (penicillin G, cloxacillin and gentamicin) is recommended. Therapy should be guided with the results of culture-sensitivity studies. Vancomycin is the drug of choice for methicillin-resistant staphylococci. In case of hemopericardium, severe anemia should be corrected by blood transfusion.

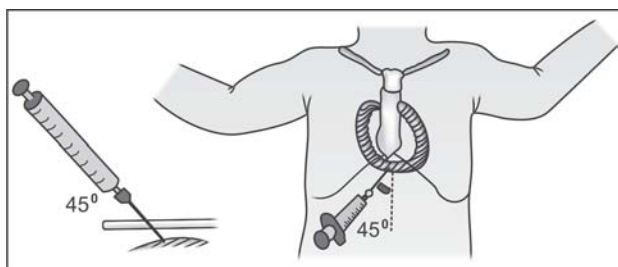


Fig. 11.1: Needle pericardiocentesis

12

Chapter

Duct-dependent Congenital Heart Disease

Diagnosis

Clinical diagnosis

With cyanotic CHD

With noncyanotic CHD

Echocardiography

Management

Prostaglandin E1 infusion

Multisystem support

Interventional catheterization

Early surgical intervention

In normal newborns, ductus arteriosus closes functionally in the first 24 hours after birth. However, there are 2 groups of congenital heart diseases (CHD) in which patency of ductus arteriosus is essential to maintain pulmonary or systemic blood flow. In these conditions, gradual closure of ductus results in clinical deterioration while complete closure leads to death.

DIAGNOSIS

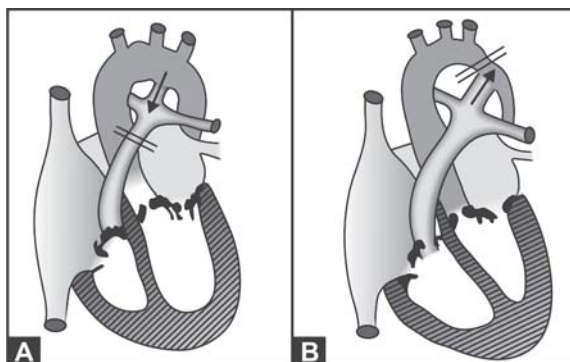
Patients with duct-dependent CHD can be clinically categorized into two groups:

1. Cyanotic group with pulmonary outflow obstruction.
2. Noncyanotic group with systemic outflow obstruction.

In both groups, most cases present in neonatal period or early infancy.

1. **Duct-dependent cyanotic CHD:** In newborns with critical obstructive lesions of pulmonary blood flow (as severe Fallot's tetralogy, tricuspid atresia, pulmonary atresia and transposition of great arteries), ductus arteriosus is essential to maintain pulmonary blood flow and oxygenation occurs by the flow of blood from aorta to pulmonary arteries through the patent ductus. These babies present in the first few days after birth with increasing cyanosis, respiratory distress and may be obstructive shock. With clinical suspicion, urgent echocardiography is essential for diagnosis and differentiation between these conditions.
2. **Duct-dependent noncyanotic CHD:** In newborns and infants with critical obstructive lesions of systemic blood flow (as critical aortic stenosis and severe coarctation of aorta), ductus arteriosus is essential to maintain systemic blood flow where the blood passes from pulmonary artery to aorta through the patent ductus. These babies present clinically with feeding difficulty and poor peripheral perfusion. In severe cases, congestive heart failure and even cardiogenic shock occurs. With clinical suspicion, urgent Doppler echocardiography is essential for diagnosis and assessment of the degree of systemic outflow obstruction.

Outflow obstruction in duct-dependent CHD



Figs 12.1A and B: (A) Pulmonary outflow obstruction (B) Systemic outflow obstruction

MANAGEMENT

Babies with these conditions should be immediately transferred to ICU where facilities for multisystem support are available.

1. **Prostaglandin EI infusion:** Prostaglandin EI is a potent and specific relaxant of the smooth muscles of ductus arteriosus. It is given in a dose of 0.05 - 2.0 mcg/kg/minute to cause dilatation of ductus arteriosus. As the drug may cause apnea, endotracheal intubation and mechanical ventilation should be considered. Available preparation of prostaglandin EI is Prostin VR amp. (500 mcg/1 ml).
2. **Multisystem support:** Oxygen therapy is essential to correct hypoxemia and it should be guided by arterial saturation and arterial blood gases. Metabolic abnormalities as hypothermia, dehydration, metabolic acidosis, hypocalcemia and hypoglycemia should be urgently corrected.
3. **Interventional catheterization:** Infants who remain severely hypoxic or acidotic in spite of above measures should be transferred to cardiac catheterization unit for urgent intervention. Examples of procedures used are Rashkind balloon atrial septostomy (in transposition of great arteries) and balloon valvuloplasty in critical aortic stenosis.
4. **Early surgical intervention:** It should be considered as soon as possible especially in conditions where interventional catheterization is not indicated.

Paroxysmal Hypercyanotic Attacks (Cyanotic Spells)

13 Chapter

Diagnosis

Increased cyanosis
Hyperpnea
Unconsciousness (may occur)
Metabolic acidosis

Management

Positioning: knee-chest position
Oxygen therapy
Sodium bicarbonate (2 mEq/kg, I.V.)
Propranolol (0.1 mg/kg, I.V.)

These attacks of increased cyanosis and hyperpnea are peculiar to infants and children with congenital cyanotic heart disease and decreased pulmonary blood flow especially Fallot's tetralogy. Several other names are used to describe these attacks as "cyanotic spells", "blue spells", "anoxic spells", "hypoxic spells", "paroxysmal hyperpnea" or "syncopal episodes".

The attacks are caused by spasm of the pulmonary infundibulum, which results in sudden increase in right ventricular outflow obstruction and decrease in pulmonary blood flow. Hypoxia and increased cyanosis occur due to inability of the right ventricular blood to reach the lungs for oxygenation. Instead, the blood in the right ventricle will flow to left ventricle (through VSD) and aorta without oxygenation.

DIAGNOSIS

The attacks are most common during the first 2 years of life with peak incidence occurring in patients between 1 and 3 months. Although the attacks may occur at any time, the majority occurs in the morning usually on awakening. Several factors can precipitate the attacks especially vigorous crying, defecation and feeding. The duration of the attack ranges from few minutes to several hours. Most attacks last for 15 - 60 minutes. Recovery is the rule and mortality is rare.

Short attacks, lasting for few minutes, are characterized by increased cyanosis and hyperpnea and may be followed by generalized weakness and sleep.

Prolonged attacks are characterized by increased cyanosis, hyperpnea and loss of consciousness due to severe hypoxia and severe metabolic acidosis. Anoxic convulsions and hemiparesis may occur. Pulse oximeter can demonstrate the low arterial oxygen saturation (below 90%) and blood gas analysis reveals arterial hypoxemia (very low PaO_2) and metabolic acidosis (low pH, low PaCO_2 and low bicarbonate). Although the condition makes no diagnostic difficulty, other causes of acute cyanosis should be considered.

Causes of acute cyanosis

Decreased environmental oxygen

- High altitude.
- Inhalation of nonphysiological gas mixture (as in fire injuries).

Impaired alveolar ventilation

- Severe airway obstruction (upper or lower).
- Severe lung pathology (as pneumonia) or lung compression (as pneumothorax).
- Severe respiratory weakness (CNS depression or respiratory paralysis).

Abnormal pulmonary blood flow

- Persistent fetal circulation.
- Acute pulmonary hypertension.
- Acute pulmonary infundibular spasm (cyanotic spells).
- Ventilation-perfusion mismatch (intrapulmonary shunt).

Poor tissue perfusion

- Shock with inadequate compensation for tissue perfusion.

- Chronic cyanosis occurs in congenital cyanotic heart disease (right-to-left cardiac shunt), abnormal hemoglobins (as methemoglobinemia) and increased reduced hemoglobin (Polycythemia and hyperviscosity).

MANAGEMENT

Emergency treatment of severe attacks includes the following:

- Positioning:** Calming the infant while held in knee-chest position over the mother's lap or shoulder may help to increase the pulmonary blood flow and may abort progression of an early attack.
- Oxygen therapy:** High oxygen concentration (near 100%) given by face mask or head box is important to correct hypoxemia and to prevent anaerobic metabolism and metabolic acidosis.
- Sodium bicarbonate:** Severe attacks are often associated with metabolic acidosis due to anaerobic metabolism and production of lactic acid. Sodium bicarbonate is given in a dose of 2 mEq/kg, I.V. over 3 - 5 minutes. The dose may be repeated as needed according to the severity of acidosis and duration of the attack.
- Propranolol:** It is an effective drug to terminate the attack, probably by relaxing the pulmonary infundibulum. It is given I.V. in a dose of 0.1 - 0.2 mg/kg. Available preparation is *Inderal amp. (1 mg/ml)*. Chronic oral propranolol therapy (1 mg/kg/6 hours) is used as a prophylactic treatment in infants with severe frequent attacks. Available preparation is *Inderal tablets (10 mg)*.

Early surgical correction should be considered in infants with severe frequent attacks.

14

Chapter

Systemic Hypertensive Crisis

Diagnosis

Diagnosis of hypertension
Diagnosis of the cause

Management

Reduction of blood pressure
Treatment of the cause

Hypertensive crisis (acute marked elevation of blood pressure) is a serious condition, which may lead to hypertensive heart failure and hypertensive encephalopathy. In children with extremely severe elevation, cerebral hemorrhage may occur.

DIAGNOSIS

Most children with hypertensive crisis are symptomatic. Neurological symptoms as headache and vomiting (due to increased intracranial pressure) are the most common. With hypertensive encephalopathy, coma or convulsions can be the initial presentation. Similarly, some children may present with acute congestive heart failure (tachycardia, tachypnea and tender liver).

Diagnosis of hypertension

Accurate measurement of blood pressure should be a routine in children presenting with headache and vomiting, coma or convulsions, or congestive heart failure.

Measurement of blood pressure can be indirectly made by the manual method (sphygmomanometer) or the automated oscilometric method (DINAMAP or Device for Indirect Noninvasive Automated Mean Arterial Pressure). With the automated method, heart rate, systolic, diastolic and mean arterial pressure (MAP) are measured. $\text{MAP} = \text{diastolic pressure} + (1/3 \text{ the difference between systolic and diastolic pressures})$. Whatever be the method used, 2 important precautions should be in mind:

1. The proper cuff size should be used because if the cuff is too wide or too narrow, false low or false high readings respectively will occur. The cuff should cover at least two-thirds of the upper arm. There are 3 available cuff sizes (newborn, infant, child).
2. The measurement should be interpreted in relation to the 95th percentile value for age (90/65 in newborns, 100/65 in infants, 110/70 in young children and 120/80 in old children).

Diagnosis of the cause

Most cases of acute hypertensive crisis are of renal origin. Acute poststreptococcal glomerulonephritis, acute renal failure and chronic renal disease are the most common. Therefore, observation for urine flow and measurement of blood urea and creatinine are important. Vascular causes (coarctation of aorta, renal artery stenosis) and endocrinal causes (pheochromocytoma) are uncommon or rare.

MANAGEMENT

Management of hypertensive crisis includes reduction of blood pressure by antihypertensive drugs and specific treatment of the causative disease.

Reduction of blood pressure

There are 3 important precautions in management of hypertensive crisis:

1. Rapid reduction of blood pressure to normal values over few hours is serious and may lead to impairment of tissue perfusion and permanent neurological sequelae. Therefore, a planned reduction to 95th percentile value should be made over 2 - 3 days (1/3 during the first 6 - 12 hours and 1/3 for each of the next 2 days).
2. As the effect of the used drugs is transient, measurement of blood pressure should be made, at least, every hour during the first day and every 2 - 3 hours during the next day or two.
3. The initial chosen drug depends on the severity of the condition. In moderate cases, sublingual nifedipine or I.V. hydralazine are satisfactory. In extremely severe cases, sodium nitroprusside continuous infusion is indicated.

Nifedipine is a calcium channel blocker with a rapid onset of action. The dose is 0.2 - 0.5 mg/kg/dose. The contents of the gelatin capsule (Epilat capsule, 10 mg) may be placed sublingually for immediate effect. As the effect is transient, the dose can be repeated every 30 - 60 minutes when necessary. Facial flushing and tachycardia are the main side effects. Hydralazine (0.2 - 0.5 mg/kg/dose, I.V.) is effective in 30 minutes with duration of action of 3 - 6 hours.

Available preparation is Apresoline amp. (20 mg/ml). Tachycardia, nausea and vomiting are the main side effects. Sodium nitroprusside (0.5 - 5.0 mcg/kg/ minute) is a highly effective drug (see shock). Furosemide (2 mg/kg/dose, I.V.) is also effective and can be repeated after 4 - 6 hours when necessary.

After initial control of blood pressure during the first 2 - 3 days, maintenance therapy can be made with oral drugs as captopril.



Fig. 14.1: Measurement of BP by DINAMAP

Treatment of the cause

Treatment of the underlying disease with the appropriate lines of therapy should be made. Anuria or severe oliguria should be managed with diuretics and low dose dopamine infusion (0.5 - 4.0 mcg/kg/minute).

15

Chapter

Acute Pulmonary Hypertension

Diagnosis

Clinical diagnosis
Doppler echocardiography
Invasive measurement of pulmonary artery pressure

Management

Hyperoxygenation
Hyperventilation
Sedation and muscle relaxation
Pulmonary vasodilatation

Acute pulmonary hypertension (due to pulmonary vasoconstriction) is a serious life-threatening condition, which may occur with severe septicemia, severe shock or severe metabolic acidosis. Alveolar hypoxia is also an important cause of pulmonary vasoconstriction, which may be localized or generalized (hypoxic pulmonary vasoconstriction or HPV).

DIAGNOSIS

Acute pulmonary hypertension should be considered in patients with hypoxia, shock, acidosis or septicemia. Clinically, severe respiratory distress with almost clear chest and chest X-ray should suggest the diagnosis. It should also be considered in mechanically ventilated patients not responding to the average respiratory support. Doppler echocardiography can confirm the diagnosis.

MANAGEMENT

Correction of the precipitating factors is the first step. Several other aspects are important especially hyperoxygenation and mechanical hyperventilation.

Management of acute pulmonary hypertension

Hyperoxygenation

Give oxygen concentration and PEEP that keep PaO_2 above 100 mm Hg. Weaning from oxygen should be very gradual.

Hyperventilation

Induce hyperventilation (increase tidal volume and rate) to keep PaCO_2 25 - 30 mmHg.

Sedation and muscle relaxation

Sedation: Give fentanyl (1 - 2 mcg/kg/hour) or midazolam (50 mcg/kg/hour).
Muscle relaxation: Give pancuronium (0.1 mg/kg, I.V. bolus) every 60 - 90 minutes.

Pulmonary vasodilatation

Give dobutamine (5 mcg/kg/minute) or isoproterenol (0.1 - 1.0 mcg/kg/minute).
Sublingual nifedipine (0.2 - 0.5 mg/kg) may also be effective.

- o Available preparation of fentanyl is Fentanyl vial (0.1 mg/2 ml).
- o Available preparation of midazolam is Dormicum ampoule (5 mg/ml).

16

Chapter

Postoperative Cardiac Surgery

Monitoring

Clinical monitoring
Laboratory monitoring
Radiological and imaging monitoring
Invasive hemodynamic monitoring

System support

Respiratory support
Cardiovascular support
Metabolic support
Hematological support

Children in the immediate postoperative period of open-heart surgery have 3 system failures; respiratory failure, cardiovascular failure (cardiogenic shock) and metabolic failure. Moreover, hematological, digestive and infectious complications are common. In addition, complications related to surgery (as cardiac tamponade, cardiac arrhythmias, hemorrhage, chylothorax) further add more problems.

In summary, all the skills and therapeutic interventions of critical care medicine are applied in these patients. Management can be divided into 2 main categories—monitoring and system support.

MONITORING

All aspects of monitoring described in shock are applied to these patients (see shock). Clinical monitoring, laboratory monitoring, radiological and imaging monitoring are important. Invasive monitoring in these patients is made by the trans-thoracic route during surgery (right atrial pressure, pulmonary artery pressure, left atrial pressure). In addition, mediastinal and pleural tubes are routinely applied. Most catheters and tubes are removed within 72 hours.

SYSTEM SUPPORT

Mechanical ventilatory support is required in all patients for few or several days. In those with acute pulmonary hypertension, hyperoxygenation and hyperventilation are required. All aspects of **cardiovascular support** described in cardiogenic shock are used in these patients. **Metabolic support** is essential to treat renal failure, electrolyte disturbance (hyperkalemia, hypocalcemia, hypomagnesemia, hypophosphatemia), hyperglycemia or hypoglycemia. **Hematological support** for coagulation defects and DIC are frequently required. Postoperative infections are a real serious problem. Fever persisting for more than the first 48 hours should stimulate a search for infection. Several cultures (blood, urine, sputum, wound, I.V. catheters) are required and vigorous **combined parenteral antibiotic therapy** should be used to control infections.



Section 4

Neurologic Emergencies

- Status Epilepticus
- Coma (Brain Failure)
- Increased Intracranial Pressure

17

Chapter

Status Epilepticus

Diagnosis

Recognition

Prolonged fit (more than 30 minutes)
Repetitive fits (without recovery)

Types or forms

Convulsive and Nonconvulsive

Complications

Respiratory
Cardiovascular
Neurologic
Metabolic

Causes

Prolonged febrile convulsions
Acute brain insult
Epilepsy

Management

Immediate management of ABC

Airway: Keep patent airway
Breathing: Give 100% oxygen
Circulation: Immediate I.V. line

Initial anticonvulsant therapy

Diazepam: 0.5 mg/kg I.V.
Phenobarbital: 15-20 mg/kg I.V.
Phenytoin: 15-20 mg/kg, I.V.

Management of refractory cases

Transfer to ICU
Diazepam constant infusion
Midazolam constant infusion
High doses of phenobarbital
Mechanical ventilation and EEG
Alternative anticonvulsants

Status epilepticus is a common and serious medical emergency, which necessitates urgent recognition and immediate vigorous treatment.

PATHOPHYSIOLOGY

Convulsions or seizures are defined as a paroxysmal abnormal electrical activity in cerebral neurons. This increased electrical activity can occur through one or more of the following three mechanisms:

1. **Increased cell membrane excitability:** It occurs due to abnormal ionic conductance of calcium, magnesium and potassium.
2. **Abnormal neurotransmitters release:** This occurs due to increased excitatory neurotransmitters or decreased inhibitory neurotransmitters.
3. **Abnormal postsynaptic receptors:** It occurs due to stimulated excitatory receptors or blocked inhibitory receptors.

The pathophysiological changes that occur in status epilepticus can be summarized in the following three aspects:

1. **Electromechanical changes:** It includes the abnormal electrical activity of cerebral neurons (detected by EEG) and the motor response of the muscles (clinically detected convulsions). These two changes are usually associated but electromechanical dissociation (continued electrical activity without motor response) can occur in fits lasting more than 1 hour or if muscular paralysis by pancuronium is done.
2. **Cerebral changes:** During a convulsive fit, cerebral oxygen consumption increases 300% and cerebral blood flow 900%. Transient and short fits are not serious and well tolerated, but prolonged fits or short repetitive fits (status epilepticus) are serious as they cause cerebral ischemia, brain edema and may be cerebral hemorrhage. The transitional period from non-serious changes (phase I) to serious changes (phase II) is 30 minutes. Brain damage occurs in convulsions lasting more than 60 minutes. The most affected areas are the neocortex, hippocampus, thalamus and cerebellum.
3. **Systemic changes:** Several respiratory, cardiovascular and metabolic changes also occur during a prolonged convulsive fit. Apnea, cyanosis, shock, heart failure, fever and metabolic acidosis are the most common. Death may occur due to airway obstruction, apnea, cardiac arrest or brain damage.

DIAGNOSIS

Recognition

Status epilepticus is defined as "convulsive fit that lasts for more than 30 minutes or frequent repetitive fits that occur without recovery of consciousness in between". On contrary to what is expected, short repetitive fits are more serious than a prolonged fit (long fits are better able to induce compensatory changes in cerebral vasculature than short repetitive fits).

Refractory status epilepticus is defined as "convulsive fit, which does not respond to initial anticonvulsant therapy or recurring in the first 30 - 60 minutes. These patients should be transferred to ICU where a prophylactic intubation and mechanical ventilation is done and a more aggressive anticonvulsant therapy is used.

Types or forms

Convulsive status epilepticus is the most common form. It can be tonic, clonic, tonic-clonic, or rarely myoclonic. It can also be generalized. Generalized tonic-clonic convulsions are by far the most common.

Nonconvulsive status epilepticus is generally uncommon or rare. It can be in the form of absence (petit mal status) or atonic fits (sudden loss of consciousness and postural tone which leads to sudden fall).

Complications

Several respiratory, cardiovascular and metabolic complications are common with status epilepticus and can be the immediate cause of death. These complications should be immediately recognized and early corrected. The mortality rate associated with status epilepticus is 5 - 10%. Death occurs due to airway obstruction, apnea, cardiac

arrest or brain damage. Residual neurologic sequelae occur in up to 25 - 30% of cases. However, it is important to remember that early and vigorous treatment of status epilepticus can dramatically reduce the acute mortality and the long-term neurologic sequelae.

Serious effects (complications) of status epilepticus

Respiratory: Airway obstruction, apnea, neurogenic pulmonary edema, aspiration pneumonia.
 Cardiovascular: Shock, heart failure, hypertension, cardiac arrest.
 Neurologic: Cerebral ischemia, brain edema, cerebral hemorrhage, brain damage.
 Metabolic: Hyperpyrexia, metabolic acidosis, hypoglycemia, hyponatremia, hyperkalemia.

Causes

Status epilepticus can be etiologically classified into three categories:

1. **Prolonged febrile convulsions:** In 90% of children with febrile convulsions, a generalized tonic-clonic convulsions lasting for few minutes or less than 15 minutes is the classic presentation. However, in 10% of cases, convulsions can be prolonged (more than 30 minutes), asymmetric or recurring during the same illness. Prolonged febrile convulsions are probably the commonest cause of status epilepticus in children below the age of 3 years. In these patients, CSF examination is essential to differentiate the condition from CNS infections as meningitis or encephalitis. It should also be remembered that fever is the sole precipitating factor of convulsions and status epilepticus in epileptic children.

Causes of status epilepticus with fever

Prolonged febrile convulsions.
 CNS infections (meningitis, encephalitis).
 Fever precipitating a status epilepticus in an epileptic child.

2. **Acute brain insult:** Acute brain disease whether primary (CNS infection, intracranial hemorrhage, cerebral infarction) or secondary (hypoxic encephalopathy, metabolic encephalopathy, drug intoxication) can be associated with status epilepticus. In this group of nonepileptic children, clinical examination and investigations should be directed to identify the causative disease (see coma).
3. **Status epilepticus in epileptic child:** More than 50% of cases of status epilepticus occur in children with recurrent convulsions (epilepsy) and 80% of these cases are idiopathic epilepsy. In epileptic children, the incidence of status epilepticus is around 10% and in more than 50% of these patients, status epilepticus is the initial presenting fit. The 2 main causes that precipitate status epilepticus in epileptic children are; (1) sudden withdrawal of anticonvulsant therapy and (2) acute febrile illness (fever is the sole precipitating factor of status epilepticus in up to 25% of cases). In the group of symptomatic epilepsy (20% of cases), cerebral malformations (lissencephaly), brain atrophy (postanoxic, postmeningitic), metabolic disease (hypocalcemia, hypomagnesemia), neurocutaneous disease (tuberous sclerosis), brain

tumors and degenerative brain diseases are the main causes. CT scan of the head and metabolic screening are indicated in this group. The mortality rate in organic epilepsy is much higher than that of idiopathic epilepsy.

MANAGEMENT

Once status epilepticus is recognized, immediate vigorous treatment is indicated to stabilize the patient and to control the ongoing convulsive fit. Management can be divided into the following three steps:

Immediate management of ABC

There is no neurologic emergency that takes priority over the basic ABC (airway, breathing, circulation). Moreover, in status epilepticus, respiratory and cardiovascular complications (airway obstruction, apnea, cardiac arrest) are the main causes of acute mortality.

1. **Airway:** Assess oral airway for patency and insert an oropharyngeal airway, if available. Excessive oral secretions are removed by gentle suctioning. It is better to keep the patient on his side to minimize the risk of aspiration.
2. **Breathing:** Give 100% oxygen by a face mask. If the patient still cyanotic or hypoventilated, a bag and mask ventilation with 100% oxygen is used. Oxygen is very essential in prolonged convulsions to prevent brain anoxia and residual brain damage.
3. **Circulation:** An I.V. line should be immediately established and a blood sample is withdrawn for investigations (especially blood sugar and serum electrolytes). If the patient is shocked, a volume expander (Ringer's lactate or saline, 20 ml/kg, I.V. over 10 minutes) should be immediately infused. In absence of shock, I.V. fluid therapy should be kept at minimum (3 ml/kg/hour) to minimize the risk of brain edema. If hypoglycemia is detected (by hemoglukotest), a 5 ml/kg of glucose 10% is given intravenously.

Initial anticonvulsant therapy

Following the initial stabilization of respiratory and cardiovascular functions (which should take only 1-2 minutes), immediate anticonvulsant therapy with the first-line drugs is used (diazepam, phenobarbital and phenytoin). It is important to remember that early vigorous therapy (with high doses) is far more effective than later therapy and it can successfully abort status epilepticus.

1. **Diazepam:** It is the first drug of choice. It is given in a dose of 0.5 mg/kg, I.V. over 3 minutes. It is a highly effective drug, which brings convulsions under control within few minutes. When necessary, the dose can be repeated after 5 minutes. When an I.V. line cannot be established, the undiluted calculated dose can be given rectally by a syringe and flexible tube. As the drug has a short duration of action (15 - 20 minutes), convulsions may recur unless a long-acting anticonvulsant (phenobarbital or phenytoin) is given simultaneously. If the drug is not effective

in 10 minutes one should proceed to other drugs. Available preparations are Valium, Stesolid or Neuril amp. (10 mg/2 ml).

2. **Phenobarbital:** It is indicated if diazepam is not effective. It is given in a dose of 15-20 mg/kg, I.V. over 3 minutes. As the drug can cause respiratory depression, close monitoring of respiration is essential. If the drug is not effective within 10 minutes, the dose can be repeated or phenytoin is given. The available preparation is Sominaletta amp. (40 mg/ml).
3. **Phenytoin:** It is indicated if both diazepam and phenobarbital are not effective. It is given I.V. in a dose of 15-20 mg/kg over 10 - 15 minutes. Close monitoring of the heart is essential as serious heart block may occur. Available preparation is Epanutin amp. (250 mg/5 ml).

After the initial control of convulsions, a maintenance dose of phenobarbital (2-3 mg/kg/dose, I.V., every 8-12 hours) and/or phenytoin (2-3 mg/kg/dose, I.V. every 8 - 12 hours) may be needed for a day or 2 to prevent recurrence.

Management of refractory status epilepticus

With failure of the first-line 3 drugs to control the convulsions within 30 - 60 minutes (refractory status epilepticus), the patient should be transferred to ICU where more aggressive measures should be taken.

1. **Diazepam constant infusion:** It can be considered especially if the initial loading dose of diazepam was briefly effective. It is given in a dose of 0.2 - 0.3 mg/kg/hour (or 2 - 3 mg/hour). Practically, 2 ml diazepam (10 mg) are added to 200 ml saline or Ringer's lactate (1 mg/20 ml) and continuous infusion is made at a rate of 40 - 60 ml/hour. The rate can be adjusted according to the response and the side effects (respiratory depression).
2. **Midazolam constant infusion:** Midazolam can be tried in a dose of 0.1 mg/kg/hour when diazepam infusion is not effective. Practically, 1 ml midazolam (5 mg) is added to 100 ml saline or Ringer's lactate (i.e. 1 mg/20 ml) and the infusion is made at a rate of 2 ml/kg/hour. Available preparation is Dormicum amp. (5 mg/ml).
3. **High doses of phenobarbital:** In a controlled environment as ICU, high doses of phenobarbital (20 mg/kg/dose, slow I.V.) can be tried and may be even repeated. The maximal daily dose of phenobarbital is 60 mg/kg. Respiratory depression if occurs should be managed with mechanical ventilation.
4. **Mechanical ventilation and alternative anticonvulsants:** With failure of the above measures, alternative anticonvulsants are the last resort. Initially, muscle paralysis with pancuronium is made (0.1 mg/kg, I.V.) and is immediately followed by endotracheal intubation and mechanical ventilation. EEG monitoring is essential to follow the brain electrical activity because the muscle paralysis induced by pancuronium abolishes the convulsions or the motor response (electromechanical dissociation). One of 3 drugs can be then tried:
 - **Paraldehyde,** if available, can be tried in a dose of 150 - 200 mg/kg, slow I.V. over 15 minutes, followed by constant infusion of 20 mg/kg/hour. A 5% solution is made (2 ml paraldehyde (2 gm) + 38 ml glucose 5%) and a glass bottle is used for infusion.

Also, the solution should not be left in a plastic syringe for more than few minutes (inactivation occurs). Coma, pulmonary embolism, pulmonary hemorrhage and hepatic toxicity are the main side effects.

- **Lidocaine** is another choice and can be given in a dose of 1 - 2 mg/kg, slow I.V. followed by constant infusion of 2 mg/kg/hour. As serious heart block and hypotension may occur, ECG monitoring and measurement of blood pressure are essential. The available preparation is Lidocaine or Xylocaine vial (1 gm/50 ml, i.e. 20 mg/ml).
- **Thiopental** is an alternative and can be given in a dose of 2 - 4 mg/kg, I.V. followed by constant infusion of 2 mg/kg/hour for 48 hours. Close monitoring of EEG and cardiovascular condition is important because severe hypotension may occur. Although initial control of seizure can be achieved, difficulties in control may arise on weaning. The available preparation is Intraval or Thiopental vial (500 mg/10 ml, i.e. 50 mg/ml).

Unfortunately, the ideal anticonvulsant drug (which rapidly controls the convulsions without causing CNS depression or other side effects) is currently not available. With the first-line drugs, diazepam is short acting, phenobarbital is respiratory depressant and phenytoin is cardiotoxic. With second-line drugs, more serious side effects may occur.

18

Chapter

Coma (Brain Failure)

Diagnosis

Level of consciousness

- Staging system
- Scoring system

Level of dysfunction

- Cortical dysfunction
- Brainstem dysfunction

Associated neurological signs

- Convulsions
- Increased intracranial pressure
- Lateralizing signs
- Meningeal irritation

Associated physical signs

- Medical illness
- Serious injury

Cause of coma

- Primary brain disease
- Secondary brain disease

Management

Investigations

- Essential investigations
- Optional investigations

Nonspecific neurologic support

- Airway control
- Breathing support
- Circulation support
- Control of convulsions
- Reduction of increased ICP
- Nutritional support
- Other systems support

Specific therapy

- Intracranial infections
- Intracranial hemorrhage
- Hypoxic encephalopathy
- Endogenous encephalopathy
- Exogenous encephalopathy

Coma is a state of prolonged unconsciousness in which the patient cannot be aroused (awakened) even with painful stimuli. It is a serious life-threatening condition, which necessitates urgent diagnostic and therapeutic measures to preserve life.

PATHOPHYSIOLOGY

Consciousness is a state of self-awareness of several widely distributed functions as motor activity, sensations, vision, hearing, speech, memory and behavior. So, consciousness is awareness of all these functions.

Consciousness depends on a continuous interaction between cerebral cortex and upper brainstem. In cerebral cortex, consciousness is present everywhere (right and left, front and back). So, any cortical lesion that impairs consciousness should be bilateral and diffuse affecting all, or almost all, cortical functions. Focal lesions in one hemisphere can cause severe neurological defect but it will not impair consciousness. In brainstem, consciousness is present in the ascending reticular activating system, which is located in midbrain and upper two-thirds of pons. So, any focal brainstem lesion affecting

midbrain and upper pons can destroy the ascending reticular activating system and impair consciousness. To summarize, coma results from one of two conditions:

1. Bilateral diffuse cortical lesion impairing all cortical functions.
2. Focal small brainstem lesion in midbrain and upper pons.

DIAGNOSIS

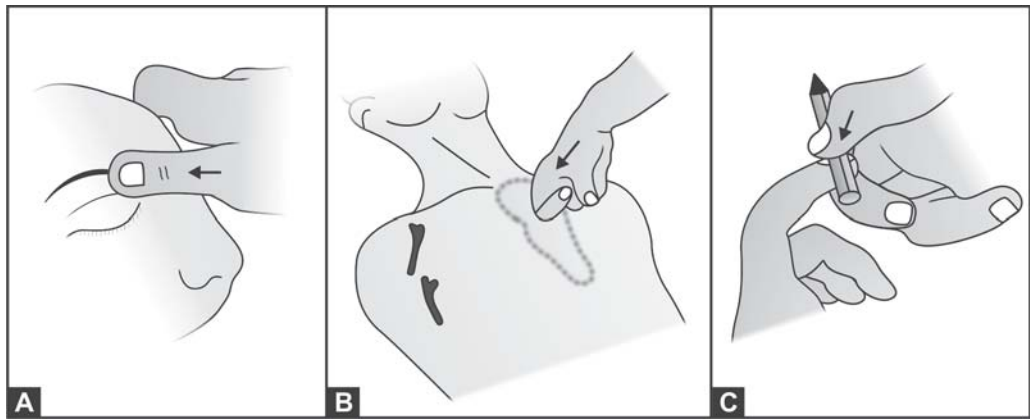
In comatose patient, although coma is the most striking clinical feature, several other clinical findings can be more serious and should be urgently detected and managed even before completing the examination.

Serious physical findings in comatose patient

Physical finding	Urgent management
Airway obstruction	Clear the mouth, extend the neck, put oral airway.
Cyanosis, respiratory distress	Give oxygen 100%.
Hypoventilation	Assisted ventilation.
Shock (hypotension)	I.V. Ringer's lactate or saline (20 ml/kg in 10 minutes).
Severe hypertension	Antihypertensive I.V. drugs.
Severe anemia	Urgent blood transfusion.
Severe dehydration	I.V. fluid therapy.
Hyperpyrexia	Measures to lower the body temperature.
Head trauma	Urgent CT and neurological consultation.
Chest or abdominal trauma	Urgent X-ray and surgical consultation.

Level of consciousness (LOC)

Assessment of the level of consciousness is made by trying to arouse (awaken) the patient by sequential sensory stimuli (to voice, to touch, to pain) and observing the response. Painful stimuli can be made by supraorbital pressure, vigorous rubbing of the sternum or pressure on fingernails and toenails by a blunt object as a pencil.



Figs 18.1A to C: Painful stimulation in comatose patient (A) Supraorbital pressure, (B) Sternal pressure, (C) Fingernail pressure

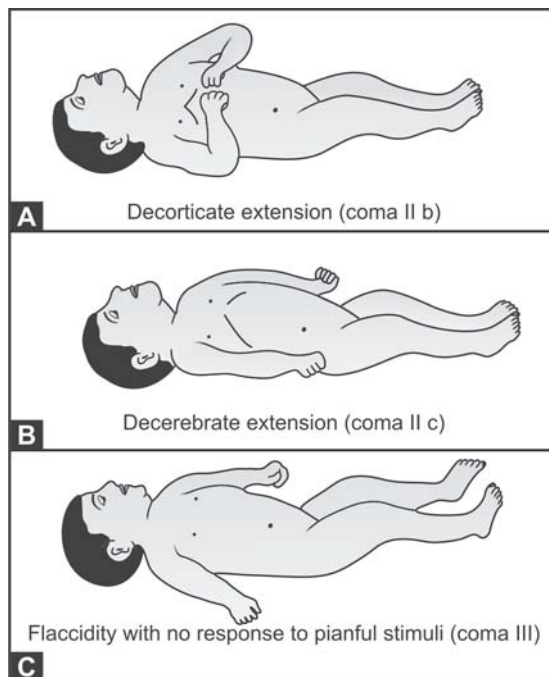
There are two systems of assessment; the staging system and the scoring system. Staging system is simple and can be used by all physicians and nurses. Scoring system is more accurate especially in follow-up but it has several disadvantages.

Staging system of the level of consciousness

- I. **Fully conscious and alert:** This is the normal consciousness.
- II. **Lethargy:** Conscious but looks sleepy or somnolent with slow reactions.
- III. **Confusion:** Conscious but with disorientation of the surroundings. Disturbed memory.
- IV. **Unconsciousness (coma):** It is divided into 4 stages:
 1. Stupor: Can be aroused briefly (less than a minute), then becomes unconscious again.
 2. Light coma: Cannot be aroused. He responds to painful stimuli by:
 - (a) Flexion withdrawal movements and moaning or
 - (b) Decorticate extension (flexion of upper limbs and extension of lower limbs) or
 - (c) Decerebrate extension (extension of the 4 limbs).
 3. Deep coma: Cannot be aroused. No response to painful stimuli. Breathing spontaneously.
 4. Deep coma with apnea: If not ventilated, brain death occurs in 4 minutes.

Brain death:

1. Deep coma (no response to painful stimuli).
2. Apnea (ventilator dependent, no respiration for 5 minutes ventilator off).
3. Absent eye brainstem reflexes (dilated fixed pupils, absent oculoccephalic reflex).
4. No hypothermia, hypotension or CNS depressant drugs.
5. Persistent findings throughout the period of observation (12 to 24 hours).



Figs 18.2A to C: Motor response in comatose patient

Modified Glasgow coma score for children

Activity	Best response	Score
Eye opening	Spontaneous or to speech	4
	To loud voice or touch	3
	To pain	2
	No response	1
Verbal response	Oriented and appropriate	5
	Words or irritable crying	4
	Cries to pain	3
	Moans to pain	2
	No response	1
Motor response	Spontaneous	6
	Flexion withdrawal to touch	5
	Flexion withdrawal to pain	4
	Decorticate extension to pain	3
	Decerebrate extension to pain	2
	No response (flaccidity)	1

Total score is 15 (4+5+6). Score below 8 indicates severe neurological injury.

Disadvantages: Inability to assess any parameter will make it impossible to count the score:

- * Eye opening cannot be assessed if the eyes are swollen and closed (trauma).
- * Verbal response cannot be assessed in intubated and ventilated patients.

Modified Morray coma score for children

Activity	Best response	Score
Motor response (cortical function)	Spontaneous	6
	Flexion withdrawal to touch	5
	Flexion withdrawal to pain	4
	Decorticate extension to pain	3
	Decerebrate extension to pain	2
	No response (flaccidity)	1
Brainstem reflexes (brainstem function)	All normal	4
	Some absent or diminished	3
	All absent but breathing	2
	All absent and apneic	1
– Pupillary reflex		
– Corneal reflex		
– Oculocephalic reflex		
– Cough/gag reflex		

Total score is 10 (6+4). It tests cortical and brainstem functions separately.

Advantages:

- * Can be used in intubated and mechanically ventilated patients.
- * Eye reflexes and respiration are included in the score.

Level of dysfunction

The level of dysfunction (cortical or brainstem) can be assessed by:

1. Motor response to painful stimuli (the 4 limbs should be tested).
2. Brainstem reflexes (both sides should be compared). It is the most important.
3. Respiratory pattern.

Level of dysfunction in comatose patient

Level	Motor response	Pupils	Respiratory pattern
Cortex	Flexion withdrawal	Small reactive	Normal or Cheyne-Stokes
Thalamus	Decorticate extension	Small reactive	Normal or Cheyne-Stokes
Midbrain	Decerebrate extension	Midposition, fixed	Neurogenic hyperventilation
Pons	No response	Pinpoint	Normal or apneustic
Medulla	No response	Small, reactive	Ataxic (irregular) breathing

Motor Response

1. **Flexion withdrawal** is a good prognostic sign as it indicates mild to moderate diffuse cortical lesion especially when associated with normal pupils and respiration.
2. **Spastic decorticate extension** (arms flexed against the chest and limbs extended) indicates a severe diffuse cortical and thalamic lesion.
3. **Spastic decerebrate extension** (four limbs are extended) indicates a midbrain dysfunction especially when associated with midposition fixed pupils.
4. **Flaccidity with no response to painful stimuli** is a bad prognostic sign as it indicates either severe cortical lesion or low brainstem lesion (pons or medulla). The prognosis is worst with ataxic breathing because the next step is apnea and brain death.
5. **Steady deterioration** with change of the motor response from flexion withdrawal to extension indicates a central transtentorial herniation due to supratentorial structural disease. In this case the level of dysfunction changes from cortical to thalamic, midbrain, pons then medulla (rostral-to-caudal deterioration or deterioration from above downwards). Urgent CT and urgent measures to reduce the increased intracranial pressure are essential.
6. **Asymmetric response:** Motor response can be symmetric (diffuse lesion), asymmetric (focal lesion). Asymmetric response (whether cortical or brainstem) is an urgent indication to CT scan of the head.

Brainstem Reflexes

1. Normal brainstem reflexes indicate a diffuse cortical lesion.
2. Unilateral loss of some or all reflexes indicates a focal brainstem lesion.
3. Bilateral loss of all reflexes with apnea indicates a brain death.

Respiratory Pattern

1. Normal breathing indicates a diffuse cortical lesion.
2. Cheyne-Stokes breathing is a periodic breathing with apneic spells.
3. Central neurogenic hyperventilation is characterized by deep inspiration and expiration.
4. Apneustic breathing is associated with respiratory pause after inspiration.
5. Ataxic breathing is a very irregular breathing in rate and rhythm. It is an ominous sign because the next step is apnea and brain death.

Diffuse lesions characterized by symmetric response are caused by CNS infections (meningitis or encephalitis) and encephalopathy (hypoxic, endogenous or exogenous). CT scan of the head is not essential.

Focal lesions characterized by asymmetric response are caused by intracranial hemorrhage, mass lesion (abscess or tumor) or focal ischemia and infarction. CT scan of the head is essential for diagnosis and differentiation between these lesions. Magnetic resonance imaging (MRI) if available is more sensitive.

Associated neurological signs

In every case of altered consciousness, other four neurological findings should be considered and excluded.

1. **Convulsions:** History, examination and follow-up for presence of convulsions are important. When present, the severity, distribution (focal or generalized), duration, frequency and response to therapy should be recorded.
2. **Increased intracranial pressure:** Acute rise of intracranial pressure is almost present in all comatose patients due to brain edema (cytotoxic or neurogenic) or excess volume (hemorrhage or mass lesion). The rise in pressure may be mild and undetected clinically or may be severe with serious or even fatal complications.

Clinical manifestations of acute increased intracranial pressure

Bulging anterior fontanel

It is a useful sign in neonates and infants.

Cushing response (hypertension and bradycardia)

Not constantly present.

Neurologic manifestations

Sluggish pupillary reaction to light.

Increased muscle tone (hypertonia).

Exaggerated deep tendon reflexes (hyper-reflexia).

Hyperventilation with deep inspiration and expiration.

Complications or manifestations of marked increase

Cerebral ischemia: Deterioration of the level of consciousness.

Tonic convulsions: Frequently recurrent or resistant to therapy.

Herniation syndromes:

Central transtentorial herniation: Steady rostral-to-caudal deterioration.

Uncal herniation: Unilateral dilated irreactive pupil.

Cerebellar tonsils herniation through foramen magnum: Neck rigidity.

- Rostral-to-caudal deterioration is detected clinically by the change of motor response from flexion withdrawal to decorticate or decerebrate extension (see above).
- Normal intracranial pressure is 0-15 mm Hg. Levels above 30 are serious.
- Intracranial pressure can be measured and continuously monitored by using intraventricular catheter, subarachnoid bolt or epidural device.
- CT scan of the head can demonstrate mass lesions, brain edema with loss of CSF spaces.

- 3. Lateralizing signs:** Detection of structural focal lesions, which manifest by lateralizing signs, is important because urgent CT scan and neurosurgical consultation can be life-saving. Motor response and cranial nerve reflexes should be made in both sides of the body. Asymmetric response should be confirmed by repeated evaluation in addition to examination of muscle tone and tendon reflexes.

Lateralizing signs in comatose patient

Focal convulsions.

Asymmetric motor response (cortical or brainstem).

Asymmetric brainstem reflexes.

Uncal herniation (unilateral dilated irreactive pupil): It is an emergency requiring urgent mechanical hyperventilation.

- 4. Features of meningeal irritation:** They include neck rigidity, neck retraction, positive Kernig's sign and Brudzinski signs. Neck rigidity may indicate meningitis, subarachnoid hemorrhage or herniation of cerebellar tonsils through foramen magnum.

Associated physical signs

Complete head-to-toe examination is essential as several useful findings can be detected. In comatose patient, although the coma is the most striking clinical feature several other clinical findings can be more serious and should be urgently detected and managed even before completing the examination.

Relevant physical signs in comatose child

Physical sign

Diagnostic significance

Serious findings

Airway obstruction
Respiratory distress
Hypoventilation
Shock
Hypertensive crisis
Severe anemia
Severe dehydration
High fever
Head trauma
Chest, abdominal trauma

Hypoxic encephalopathy
Hypoxic encephalopathy, metabolic acidosis
Drug intoxication, severe brain insult
Hypoxic-ischemic encephalopathy
Hypertensive encephalopathy
Hypoxic-anemic encephalopathy
Severe gastroenteritis, diabetic ketoacidosis
CNS infection
Intracranial hemorrhage
Internal hemorrhage

Other findings

Fever
Jaundice and hepatomegaly
Hepatomegaly
Generalized edema
Renal mass
Purpuric eruption

CNS infection
Acute hepatic failure
Reye syndrome
Acute renal failure, water intoxication
Acute renal failure
Intracranial hemorrhage, meningococcemia

It is important to remember that eye examination is the most important single step in examination of the comatose patient, as several useful information can be obtained. **The eye is the window of the brain.**

Value of eye examination in comatose patient

Evidence of the cause

Sunken eyes (dehydration), jaundice (hepatic failure), subconjunctival hemorrhage (ICH).

Pupillary changes: Pinpoint (organic phosphorus, opiates).

Small (sedatives, antihistamines, anticonvulsants).

Dilated (atropine, local instillation of mydriatics).

Level of brain dysfunction

Small reactive pupils (cortical or thalamic) (Intact brainstem reflexes

Midposition, fixed pupils (midbrain) indicates that the coma is due

Pinpoint pupils (pons) to diffuse cortical lesion)

Evidence of lateralization

Asymmetric brainstem reflexes.

Uncal herniation (unilateral dilated irreactive pupil).

Diagnosis of brain death

Bilateral absent brain stem reflexes (Diagnosis of brain death

Bilateral dilated irreactive pupils (2, 3) is made if these signs

Absent oculocephalic and oculovestibular persist for 12 -24 hours in absence of hypothermia,

reflexes (3, 4, 6, 8) hypotension or CNS

Absent corneal reflex (5, 7) depressant drugs)

Absent cough/gag reflexes (9, 10)

Unresponsiveness and apnea

- **Oculocephalic reflex:** It is a specific reflex for comatose patients, which can test both midbrain and pontine functions. Turning the head to one side (with open eyes) results in conjugate deviation of the eyes to the opposite direction (Doll's eyes). The reflex can be elicited in the four directions (right, left, up and down).
 - Present reflex indicates an intact brainstem and indicates that the coma is due to a diffuse cortical disease and the brainstem is released from the cortical inhibition.
 - Absent reflex in one direction indicates a focal brainstem lesion.
 - Absent reflex in all directions indicates a brainstem death (brain death).
- **Oculovestibular reflex:** It has the same significance of oculocephalic reflex.
 - Irrigation of one auditory canal with ice water (up to 120 ml over 2 minutes) results in a conjugate deviation of the eyes towards the irrigated side. Testing of the other side should not be made except after 5 minutes.
 - Simultaneous irrigation of both ears with cold water results in downward deviation.
 - Simultaneous irrigation of both ears with hot water results in upward deviation.

As the test is more resistant to injury, it should be done if oculocephalic reflex is absent to confirm the diagnosis of brain death.

Cause of coma

Accurate identification of the cause of coma depends on a collection of data gained by history, examination and investigations. **History taking** should include history of head trauma, drug intoxication or insecticide, onset and course of illness. Past history of diabetes, renal disease or blood disease is particularly important. Fever with the onset of illness greatly suggests CNS infection.

Causes of coma in children

Primary brain lesion

CNS infections

- Meningitis
- Encephalitis
- Brain abscess
- Cortical thrombophlebitis
- Cerebral malaria
- Severe septicemia (toxins)

Intracranial hemorrhage

- Traumatic head injury
- Nontraumatic causes
 - Hemophilia, DIC
 - ITP
 - Sickle cell anemia
 - Polycythemia
 - Ruptured aneurysm
 - Arteriovenous malformations

Focal ischemia and infarction

Postepileptic (post-ictal) coma

- Status epilepticus

Advanced brain tumor

Secondary brain lesion (Encephalopathy)

Hypoxic encephalopathy

Hypoxic hypoxic encephalopathy

- Severe airway obstruction
- Severe respiratory failure
- Post-cardiopulmonary arrest

Hypoxic ischemic encephalopathy

- Advanced shock (any cause)

Hypoxic anemic encephalopathy

- Severe blood loss
- Severe acute hemolysis

Endogenous encephalopathy

Acute organ failure

- Acute renal failure
- Acute hepatic failure
- Diabetic ketoacidosis, hypoglycemia

Water and electrolyte disturbance

- Water intoxication or dehydration
- Severe acidosis or alkalosis
- Hypo or hyperelectrolytemia (Na, Ca, Mg)

Errors of metabolism

- Organic acidemias
- Hyperammonemia

Exogenous encephalopathy (Poisoning)

- Drug intoxication
- Environmental toxins

According to presence or absence of lateralizing or focal signs, causes of coma can be generally classified into two groups; structural (focal) and metabolic (diffuse). With focal lesions, urgent CT scan of the head is indicated and neurosurgical consultation is necessary especially in presence of intracranial hemorrhage or mass lesion. Uncal herniation should be routinely excluded.

Causes of coma according to presence or absence of lateralizing signs

Structural or focal lesion

- Intracranial hemorrhage
- Focal ischemia and infarction
- Mass lesion (abscess, tumor)

Metabolic or diffuse lesion

- Meningitis and encephalitis
- Encephalopathy (Hypoxic, Endogenous, Exogenous)

Silent or isolated coma (i.e. not associated with any other neurological or physical findings) should always suggest **exogenous encephalopathy** (drug intoxication) as a first possibility. The possibility becomes greater when the coma is associated with small pupils and hypoventilation (slow shallow respiration with CO₂ retention). It should be remembered that negative history is not conclusive as parents may deny the exposure to drugs or poisons and it should also be remembered that poisoning may occasionally be criminal (non-accidental poisoning).

Common poisons in comatose patient

Poison	Clinical manifestations
Narcotics (anticonvulsants, antihistamines)	Miosis, hypoventilation
Salicylates	Acidosis, hyperventilation
Organic phosphorus	Pinpoint pupils, increased secretions
Alcohol should be considered in adolescents	

MANAGEMENT

Management of comatose patients can be divided into three aspects; investigations, nonspecific neurologic support and specific therapy of the causative disease.

Investigations

Several investigations are usually required in comatose patients to identify the causative disease and to guide therapy. These investigations may be classified into early essential and later optional investigations.

Possible investigations in comatose patient

Urgent investigations (In all cases)

- Blood gas analysis: In all cases to detect hypoxemia, CO₂ retention or metabolic acidosis.
- Serum electrolytes (Na, K, Ca and Mg): To detect low or high levels.
- Renal function (blood urea and creatinine): To detect acute renal failure.
- Blood sugar level: To detect hypoglycemia or hyperglycemia.

Other optional investigations (With clinical suspicion)

- Sepsis screen (CBC, ESR, CRP, blood culture): In suspected septicemia or meningitis.
- Blood film for malaria: In suspected cerebral malaria.
- Lumbar puncture and CSF examination: In suspected intracranial infection.
- Liver function (bilirubin, transferases, ammonia): In suspected acute hepatic failure.
- Coagulation study (platelets, PT, PTT): In suspected bleeding disorder.
- CT scan of the head: In head trauma or lateralizing signs.
- Chest X-ray: In respiratory distress or chest trauma.
- Abdominal X-ray and ultrasound: In abdominal trauma or abdominal mass.
- Metabolic screen: In suspected errors of metabolism.
- Toxic screen and analysis of gastric contents: In suspected poisoning.

Nonspecific neurologic support

Comatose patient should never be left unattended and he should be accompanied by a nurse throughout the 24 hours. Ideally, he should be transferred to an intensive care unit where facilities for continuous monitoring and mechanical ventilatory support are available.

Nonspecific neurologic support aims to preserve brain functions, to prevent secondary injury, to provide nutritional support and to treat the complications if present. Management should start, as always, with the ABC (Airway + Breathing + Circulation). Control of convulsions and increased intracranial pressure should come next.

1. **Airway:** Measures to keep the airway patent are the initial step. The mouth is opened and any food remnants or foreign bodies should be removed. Suctioning of the oropharynx is made, the neck is slightly extended and an oropharyngeal airway is inserted.
2. **Breathing:** All comatose patients should receive oxygen. An initial concentration of 40%, given by a head box (in infants) or face mask or nasal catheter (in children) is usually sufficient. Oxygen therapy should continue until the patient regains consciousness. Severe respiratory depression with CO₂ retention necessitates mechanical ventilation. It is currently recommended to mechanically ventilate all comatose patients to ensure adequate oxygenation. It is also recommended to achieve a supraphysiological level of oxygenation (PaO₂ above 100 - 120 mm Hg).
3. **Circulation:** Following patent airway and oxygen administration, an I.V. line should be immediately inserted. Blood pressure should be kept within normal limits and shock (hypotension) or hypertension, if present, should be promptly corrected. When the possibility of diabetic ketoacidosis is standing, start therapy with Ringer's lactate or normal saline (see diabetes). Otherwise, I.V. fluid therapy is made of glucose 10% and saline in a ratio of 4:1 in an amount equal to the daily maintenance requirements. When renal failure is excluded, potassium chloride solution should be added. Dehydration and/or electrolyte disturbances should also be corrected (see I.V. fluid therapy). An accurate fluid balance of intake and output should be made and recorded in a flow sheet. Daily weighing is essential.
4. **Control and prevention of convulsions:** If convulsions are present, vigorous therapy to control the convulsions and to prevent further fits is essential. Diazepam (Valium) is given I.V. in a dose of 0.5 mg/kg to control the ongoing convulsive fit. If it is not effective within 10 minutes, phenobarbital is given I.V. (15-20 mg/kg). Continued convulsions for another 10 minutes necessitates I.V. phenytoin (Epanutin) in a dose of 15-20 mg/kg. Following the initial control, a maintenance therapy is made with I.V. phenobarbital (2-3 mg/kg every 8-12 hours) and/or phenytoin (2-3 mg/kg every 8-12 hours). Treatment is continued until convulsions become unlikely to occur, then the drugs are gradually discontinued.
5. **Reduction of the increased intracranial pressure:** Measures to reduce the increased ICP depend on the severity of the condition:

- In emergency situations of impending or frank herniation (raustral-to-caudal deterioration, unilateral or bilateral dilated irreactive pupils), rapidly-acting measures are indicated. Head elevation 30° in neutral position is useful to enhance cerebral venous return. Hyperventilation to keep PaCO₂ 25-30 mmHg is the most effective measure in few minutes. Drugs as lidocaine (1.5 mg/kg, I.V. bolus) or mannitol 20% (5 - 10 ml/kg, I.V. over 30 minutes) are also rapidly effective.
 - In less urgent situations, slowly-acting measures can be used. They include fluid restriction to 60-70% of daily requirements, diuretics as furosemide (0.5-1.0 mg/kg, I.V. every 4-6 hours) and may be steroids (dexamethasone or methylprednisolone).
 - It is also important to prevent conditions that increase cerebral ischemia (as hypoxemia, hypotension, hypoglycemia).
 - Surgical removal of big masses may also be considered.
- 6. **Care of the respiratory system:** Prophylactic chest physiotherapy and frequent suctioning are important to prevent lung collapse. A nasogastric tube is inserted and gastric contents are aspirated to avoid vomiting and possible inhalation. Apart from anticonvulsants, all drugs that may suppress the respiration should be avoided. Complications as pulmonary infection or pulmonary edema should be treated. Severe respiratory depression with CO₂ retention (PaCO₂ above 60 mm Hg) necessitates mechanical ventilation.
- 7. **Care of the gastrointestinal system:** Stress gastric ulceration is common in comatose patients. An antacid as aluminium hydroxide gel (Epicogel or Alkagel) is given through the nasogastric tube every 4 hours in an amount of 10-15 ml/time. Prevention of constipation and fecal impaction is also important. Lactulose may be used through the nasogastric tube to prevent or treat constipation.
- 8. **Care of the eyes and skin:** An antibiotic eye drop and an ointment are used to prevent infection and corneal ulcerations. Frequent change of position is important to avoid bedsores. A urine bag is placed to collect urine and to avoid contact with the skin. Fecal matters should be immediately removed and proper care of the napkin area is important. Skin infections should be adequately managed by both local and systemic measures.
- 9. **Prevention of infection:** Frequent inspection of the I.V. sites is important. Repeated urine analysis and urine and blood cultures are indicated in prolonged coma. A prophylactic broad-spectrum antibiotic may be used when the risk is considerable. Infections, if present, should be treated urgently and adequately with appropriate antibiotic therapy.
- 10. **Nutritional support:** When coma persists for more than 2-3 days, nasogastric tube feeding should be started to provide the nutritional requirements. Do not forget that tube feeding was originally designed for comatose patients (see tube feeding). When tube feeding is not tolerated for any reason, total parenteral nutrition should be considered (see therapeutic intervention, nutritional support).

Specific management

Treatment of the underlying cause of coma is an essential step in management. The cause could be known by collection of data gained by detailed history, thorough examination and relevant investigations.

1. **Intracranial infections:** Until a bacterial origin is excluded, all patients with CNS infection (meningitis, encephalitis, or brain abscess) should receive vigorous I.V. antibiotic therapy. An initial therapy with ampicillin (200 mg/kg/day, in 4 divided doses) and one of the third generation cephalosporins as cefotaxime (200 mg/kg/day, in 2 divided doses) is recommended. In bacterial meningitis, antibiotic therapy may be changed according to the clinical response and results of CSF and blood cultures, and duration of therapy is at least for 10 - 14 days. In brain abscess, urgent neurosurgical consultation and surgical drainage is important and antibiotic therapy is continued for 6 weeks. In encephalitis due to herpes simplex infection, acyclovir should be used I.V. in a dose of 10 mg/kg/dose, every 8 hours for 7-10 days. Available preparation is Zovirax amp. (250 mg/5 ml).
2. **Head trauma and intracranial hemorrhage:** Initial CT scanning of the head is essential. Urgent neurosurgical consultation and possible surgical intervention are indicated.
3. **Hypoxic encephalopathy:** In case of severe hypoxia due to severe respiratory failure, mechanical ventilation is necessary. Severe cardiogenic or septicemic shock requires inotropic therapy with dopamine and/or dobutamine infusion. Severe acute anemia should be urgently corrected by packed red cell transfusion (5-10 ml/kg).
4. **Endogenous encephalopathy:** Diabetic coma requires parenteral insulin therapy (see diabetes). In hepatic or renal coma, several specific measures are required (see acute hepatic failure and acute renal failure). Hyponatremic dehydration requires specific therapy with I.V. fluids and hypertonic saline infusion (see I.V. fluid therapy).
5. **Exogenous encephalopathy (Drug intoxication):** In case of accidental poisoning (with a medicine, cleaning agent, insecticide, paints, petroleum product or a plant), several general rules should be followed:
 - a. Supportive measures and treatment of any symptom as it appears.
 - b. Decrease absorption of the toxin by emptying the stomach (gastric lavage).
 - c. Increase excretion of the toxin by forced diuresis (give furosemide and mannitol I.V. and increase I.V. fluids to 1.5 the maintenance).
 - d. Poison identification: By history, taking sample of the agent and the container, taking samples of blood, urine and vomitus to be sent for toxicology center.
 - e. Give specific antidote (if available): See poisoning.

19

Chapter

Increased Intracranial Pressure

Diagnosis

Clinical diagnosis

- Bulging fontanel
- Nonspecific manifestations
- Neurological manifestations

Complications

- Cerebral ischemia
- Tonic convulsions
- Herniation syndromes

Diagnostic procedures

- CT scan of the head
- Monitoring of ICP
 - Intraventricular
 - Subarachnoid or epidural
 - External

Management

Rapidly acting measures

- Head elevation 30° in midline position
- Hyperventilation (PaCO₂ 25-30 mm Hg)
- Drugs: Lidocaine, mannitol

Slowly acting measures

- Fluid restriction (2 ml/kg/hour)
- Diuretics: Furosemide
- Steroids: Dexamethasone, methylprednisolone

Other measures

- Prevention of convulsions and hyperpyrexia
- Prevention of hypoxemia and hypotension
- Prevention of hypoglycemia
- Removal of CSF (risky)
- Surgical removal of big masses

Acute rise of intracranial pressure (as in intracranial hemorrhage, CNS infection or acute encephalopathy) is a serious life-threatening condition, which may lead to pressure necrosis, cerebral ischemia and herniation syndromes. On the other hand, chronic or slowly rising intracranial pressure (as in hydrocephalus or brain tumors) does not represent an immediate threat to life.

PATHOPHYSIOLOGY

The intracranial volume consists of the brain volume (80%), cerebral blood volume (10%) and CSF volume (10%). Because of the rigid skull, the intracranial volume cannot expand significantly. Therefore, any significant increase in the volume of any component (brain volume, cerebral blood volume (CBV) or CSF volume) will result in significant rise of intracranial pressure. In addition, any pathological volume (abscess, tumor, extravascular blood) will also lead to increased intracranial pressure.

- 1. Brain volume:** Brain accounts for 80% of intracranial volume. With acute brain insult, the brain volume increases by edema fluid (brain edema), which results in acute rise of intracranial pressure. According to the mechanism and site of accumulated fluid, there are three types of brain edema:

- a. **Cytotoxic brain edema:** It is an intracellular edema secondary to cellular injury and cellular swelling, and it is primarily seen in the gray matter. It occurs with head trauma, CNS infection, hypoxic-ischemic encephalopathy and metabolic encephalopathy (as Reye syndrome, fulminant hepatic failure, uremia and hyponatremia). It is the most common type and the least responsive to therapy.
 - b. **Vasogenic brain edema:** It is an extracellular edema due to increased permeability of brain capillary endothelial cells (leaky vessels), and it is mainly seen in white matter. It occurs with CNS infections and around pathological masses (tumor, abscess, intracranial hematoma). As the neurons are not injured, the response to therapy is excellent.
 - c. **Interstitial brain edema:** It occurs due to increased CSF pressure (obstructive lesion) or CSF production. Treatment of this type is by shunt operation or by drugs that reduce CSF production (as acetazolamide).
2. **Cerebral blood volume (CBV):** One third of cerebral blood is present in brain tissue and two-thirds in dural sinuses and subarachnoid veins. Cerebral blood volume depends on cerebral blood flow (CBF), which is kept constant and autoregulated by two mechanisms:
 - a. **Pressure autoregulation:** Cerebral blood flow depends on the cerebral perfusion pressure (CPP) which is the pressure difference between mean arterial pressure (MAP) and intracranial pressure (ICP), i.e. $CPP = MAP - ICP$.
 - **Under normal conditions**, cerebral blood flow remains constant within a wide range of arterial blood pressure (between 50 - 150 mmHg). With arterial blood pressure below 50 mm Hg or above 150 mm Hg, cerebral blood flow will decrease or increase respectively.
 - **With acute brain insult**, this pressure autoregulation is altered or even lost. Therefore, any change in arterial blood pressure or intracranial pressure will greatly affect the cerebral perfusion pressure (CPP) and cerebral blood flow (CBF). Both arterial hypotension and increased intracranial pressure will result in reduction of cerebral perfusion pressure and cerebral blood flow (cerebral ischemia).
 - Arterial hypotension → reduced CPP → reduced CBF → cerebral ischemia.
 - Increased ICP → reduced CPP → reduced CBF → cerebral ischemia.
 - b. **Metabolic autoregulation:** Cerebral blood flow is very sensitive to changes in $PaCO_2$ and PaO_2 . In contrast to pressure autoregulation, metabolic autoregulation is resistant to injury and is not lost in acute brain insult.
 - **Pressure of arterial carbon dioxide ($PaCO_2$):** Cerebral blood flow is very sensitive to changes in $PaCO_2$ and the relation is almost linear (1 mm Hg change in $PaCO_2$ results in 3-4% change in cerebral blood flow). Hypoventilation (raised $PaCO_2$) results in an increase in CBF and hyperventilation (lowered $PaCO_2$) results in a decrease in CBF.
 - Hypoventilation → increased $PaCO_2$ → increased CBF → increased ICP.
 - Hyperventilation → reduced $PaCO_2$ → reduced CBF → reduced ICP.

- Depending on this relationship, *hyperventilation is therapeutically used to decrease CBF and intracranial pressure.*
- **Pressure of arterial oxygen (PaO_2):** Arterial hypoxemia (low PaO_2) results in rise in CBF and ICP. At PaO_2 below 50 mm Hg, progressive increase of CBF occurs and at 25 mm Hg, CBF increases 300%. On the other hand, PaO_2 above normal (hyperoxia) does not result in reduction of CBF.
 - Depending on this relationship, avoidance and correction of hypoxemia is an important step in treatment of increased ICP.
- 3. **CSF volume:** Cerebrospinal fluid (CSF) represents the remaining 10% of intracranial volume. Part of CSF is present inside ventricles but most CSF is present in subarachnoid spaces (especially subarachnoid cisterns), which is in direct communication with CSF in intraspinal spaces. With increased ICP, initial compensation occurs through transfer of CSF from intracranial to intraspinal spaces, but with further increase in ICP, this compensatory mechanism is exceeded and a sharp rise of ICP occurs. Increased CSF volume occurs with obstruction to CSF flow or with increased CSF production, and both lead to increased ICP.
- 4. **Pathological volume:** Pathological masses (abscess, tumor) or extravascular blood associated with head trauma (epidural, subdural or intracerebral hematoma) are also associated with increased ICP.

Causes of increased intracranial pressure according to mechanism

Brain edema

Cytotoxic brain edema: With CNS infections and encephalopathies.

Vasogenic brain edema: With CNS infection and around pathological masses.

Interstitial brain edema: With increased CSF pressure or CSF production.

Increased cerebral blood flow

Systemic hypertension above 150 mmHg.

Hypoxemia (low PaCO_2) and hypercarbia (high PaCO_2).

Hyperpyrexia.

Convulsions (CBF increases 900%).

Increased CSF volume

Obstruction to CSF flow.

Increased CSF production.

Pathological volume

Pathological mass (abscess, tumor).

Extravascular blood (epidural, subdural or intracerebral hematomas).

- Cytotoxic brain edema is the most common and most serious cause of acute increased intracranial pressure. It is also the least type responsive to therapy.

DIAGNOSIS

Normal intracranial pressure is 0-15 mm Hg (or 0-200 cm H_2O). Clinical manifestations of increased ICP occur when the pressure is above 25 - 30 mm Hg. Diagnosis of increased ICP can be made clinically and may be confirmed by some diagnostic procedures.

Clinical diagnosis

Unfortunately, the most reliable signs of increased intracranial pressure (bulging fontanel, papilledema) can be absent in acute cases.

- **Mild rise of intracranial pressure** may not be detected clinically or nonspecific manifestations as headache and vomiting may be present.
- **Moderate rise of ICP** usually present with neurological manifestations especially disturbed consciousness (confusion, coma) and sluggish pupillary reaction to light.
- **With marked rise of ICP**, complications as cerebral ischemia, tonic convulsions and herniation syndromes can occur.

Clinical manifestations of acute increased intracranial pressure

Nonspecific manifestations

Headache and vomiting.

Cushing response (hypertension and bradycardia) is not constantly present.

Neurological manifestations

Disturbed consciousness (lethargy, confusion or coma).

Sluggish pupillary reaction to light and may be pupillary dilatation.

Increased muscle tone (hypertonia) and exaggerated deep tendon reflexes (hyper-reflexia).

Hyperventilation with deep inspiration and expiration.

Complications or manifestations of marked increase

Cerebral ischemia: Deterioration of the level of consciousness.

Tonic convulsions: Frequent recurrent or resistant to therapy.

Herniation syndromes:

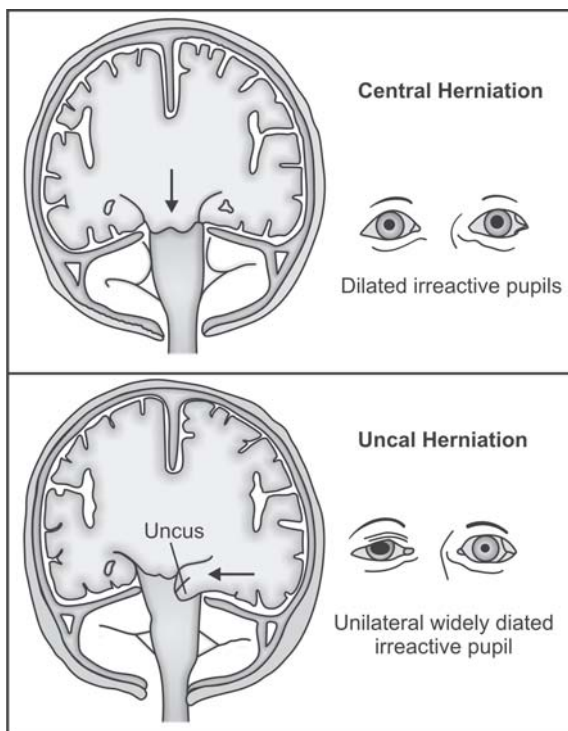
Central transtentorial herniation: Steady rostral-to-caudal deterioration.

Uncal herniation: Unilateral dilated irreactive pupil.

Cerebellar tonsil herniation through foramen magnum: Neck rigidity.

- **Cerebral ischemia** occurs due to compression of cerebral vessels by edematous brain tissue and reduced cerebral perfusion pressure ($CPP = MAP - ICP$). When CPP is below 50 mmHg, cerebral ischemia occurs. Similarly, when arterial BP is below 60 mm Hg, cerebral ischemia also occurs.
- **Central transtentorial herniation** occurs due to downward shift of supratentorial compartment across the tentorium cerebelli. It usually occurs with supratentorial focal lesions but it may also occur with metabolic encephalopathy. Rostral-to-caudal deterioration (from above downwards) is detected clinically by the change of motor response from flexion withdrawal to decorticate or decerebrate extension. Immediate hyperventilation is indicated to reduce ICP.
- **Uncal herniation** is a lateral shift of brain tissue from one side across the middle line. The uncus (part of hippocampal gyrus) is pushed laterally against the fixed free edge of the tentorium leading to unilateral third nerve injury (unilateral dilated irreactive pupil). It usually occurs with unilateral focal temporal lesion (as subdural or extradural hematoma). Hemiparesis on the other side may also be present. Immediate hyperventilation is also indicated to lower the increased ICP.
- **Medullary herniation** through foramen magnum can iatrogenically occur if lumbar puncture is made with a markedly elevated ICP. Clinical manifestations include coma, hypotonia, hypotension, slow respiration or apnea.

Herniation syndromes



Diagnostic procedures

Confirmation of the clinical diagnosis of increased intracranial pressure can be made by CT scan or by direct invasive measurement and monitoring of intracranial pressure. Obviously, invasive techniques should be only done by a neurosurgeon in an intensive care unit. It should be remembered that urgent management of impending or frank herniation should be made on clinical basis without waiting for confirmation.

Diagnostic procedures of increased intracranial pressure

CT scan of the head

Differentiation between cytotoxic (gray matter) and vasogenic (white matter) brain edema. Detection of focal lesions (abscess, tumor, hematomas).

Detection of increased ICP by demonstration of generalized loss of CSF spaces:

- Grade I:** Loss of supratentorial spaces (loss of sulci cerebri, interhemispheric fissure and/or lateral ventricles).
- Grade II:** Loss of all supratentorial spaces and some infratentorial spaces (chiasmatic cystem and/or quadrigeminal cystem and/or interpeduncular cystem).
- Grade III:** Complete loss of all supratentorial and infratentorial spaces.

Measurement and monitoring of ICP

Since the cranium and its contents form a closed system, all structures within it have the same pressure. Depending on this fact, measurement can be made by:

- Intraventricular catheter: Most accurate but risky (infection, bleeding).
- Subarachnoid bolt: Less accurate but simple and safe.
- Epidural devices: Very safe (not communicating with CSF spaces).
- External monitors via anterior fontanel: Noninvasive but not accurate.

MANAGEMENT

Measures to reduce the elevated intracranial pressure are mainly directed to decrease the cerebral blood volume and brain volume. Other measures as removal of CSF or surgical removal of masses may be occasionally needed (see below). It may be therapeutically useful to classify these measures according to the onset of action into two groups; rapidly acting measures and slowly acting measures.

Measures to reduce the increased ICP according to onset of action

Rapidly acting measures (in impending or frank herniation)

Head elevation 30° in neutral position.

Hyperventilation to keep PaCO_2 25 - 30 mmHg.

Drugs as lidocaine (1.5 mg/kg, I.V.) or mannitol 20% (5-10 ml/kg, I.V. over 30 minutes).

± Removal of CSF via intraventricular catheter (risky).

Slowly acting measures

Fluid restriction (2 - 3 ml/kg/hour).

Furosemide: 0.5 - 1.0 mg/kg, I.V. every 4 - 6 hours.

Steroids: Dexamethasone or methylprednisolone (see below).

Rapidly-acting measures

These measures are indicated in severe life-threatening conditions as impending or frank herniation especially during the first 48 hours. These measures act mainly through reduction of cerebral blood volume.

1. **Head elevation 30° in neutral position:** Moderate elevation of the head (30°) is effective in enhancing cerebral venous return and reduction of cerebral blood volume. Also, the head should be kept in midline because turning the head to one side will reduce cerebral venous return. Higher elevation (above 40°) should be avoided, as it will decrease arterial blood pressure and cerebral perfusion pressure.
2. **Hyperventilation:** Endotracheal intubation and induced mechanical hyperventilation is the most effective dramatic measure that can reduce the raised ICP within minutes. Muscle paralysis with pancuronium may also be required. As cerebral blood flow is directly proportionate to PaCO_2 , reduction of PaCO_2 through hyperventilation is immediately accompanied with reduction of cerebral blood flow and intracranial pressure. It is only indicated in the first day or two with clinical features of impending or frank herniation. A moderate degree of hyperventilation is required to keep PaCO_2 between 25 - 30 mm Hg. Reduction of PaCO_2 from 40 to 25 mm Hg will result in 50% reduction of cerebral blood volume. In emergency situation, hyperventilation should be continued till pupillary equality and reactivity return to normal. Generally, hyperventilation should not be continued for more than a day or two. Hyperventilation after these 2 days is harmful because it will decrease the cerebral perfusion pressure and cause more cerebral ischemia. During hyperventilation, it is also important to reduce PEEP to 3 - 4 cm H_2O because high PEEP will impair cerebral venous return and increase cerebral blood volume.

3. **Drugs:** Lidocaine (1.5 mg/kg, I.V. bolus) is quite effective for rapid reduction of intracranial pressure and it is recommended immediately before intubation to prevent further rise of ICP which occurs with stressful procedure as intubation. Thiopental (1 - 2 mg/kg, I.V. bolus) has the same effect but hemodynamic instability is a major disadvantage. Mannitol is an osmotic diuretic, which is effective in few minutes. It causes reduction of increased ICP through 3 mechanisms; (1) diuretic effect (it enhances the movement of brain interstitial free water into the vascular spaces), (2) cellular dehydrating effect (by its osmotic load, it draws fluid out of brain cells to blood stream) and (3) cerebral vasoconstrictor effect (it reduces cerebral blood flow). Mannitol 20% is given I.V. in a dose of 5 - 10 ml/kg over 30 minutes every 6 hours for a maximum of 2 days. Lower doses are preferable to avoid hyperosmolarity (greater than 340 mOsm) which may eventually lead to rebound intracranial hypertension. With mannitol therapy, volume overload should be avoided which may occur if the patient is anuric.

Slowly-acting measures

These measures are mainly useful in vasogenic brain edema characterized by extracellular accumulation of water. Their effect in cytotoxic brain edema is less evident.

1. **Fluid restriction:** Fluid intake should be restricted to 60 - 70% of total daily requirements (three ml/kg/hour) and in severe cases, reduction to 50% (2 ml/kg/hour) can be made as long the vital organ perfusion is maintained (adequate blood pressure, peripheral perfusion and urine output). Fluid restriction is contraindicated in patients with shock as it will lead to more cerebral ischemia.
2. **Diuretics:** Furosemide is a loop diuretic which causes reduction of increased ICP through three mechanisms; (1) diuretic effect (as mannitol but with slower onset of action), (2) it reduces further accumulation of water inside brain cells through reducing sodium transport, and (3) it may also inhibit CSF formation. It is given I.V. in a dose of 0.5 - 1.0 mg/kg every 4 - 6 hours. As the drug is less effective than mannitol and has a slower onset of action, it is advisable to use both drugs to achieve the rapid effect and to avoid high doses of mannitol, which may lead to volume overload and hyperosmolarity.
3. **Steroids:** These drugs are only useful in reducing vasogenic brain edema around brain tumors, extravascular blood or with surgically induced edema. There is no evidence that these drugs have any effect in cytotoxic brain edema that occurs with hypoxic-ischemic encephalopathy or metabolic encephalopathies. When indicated, either dexamethasone (0.25 mg/kg, I.V. every 6 - 12 hours) or methylprednisolone (1 - 2 mg/kg, I.V. every 6 hours) can be used for a maximum period of 2 days.

Other measures

Several other important measures should be considered in management of children with increased intracranial pressure:

- **Conditions that increase cerebral blood flow (CBF)** as hyperpyrexia and convulsions should be prevented or urgently corrected.

- *Conditions that cause cerebral ischemia* as hypotension, hypoxemia and hypoglycemia should also be prevented or urgently corrected. A supraphysiological level of oxygenation (PaO_2 above 100 - 120 mm Hg) prevents further cellular injury and further rise of ICP.
- *Other measures to reduce ICP* may also be considered. Reduction of CSF volume through lumbar puncture should be avoided as it may lead to fatal medullary herniation. Surgical removal of big hematomas may be considered and it necessitates neurosurgical consultation.



Section 5

Metabolic Emergencies

- Temperature Abnormalities
- Water Imbalance
- Acid-base Disorders
- Electrolyte Disorders
- Acute Renal Failure
- Acute Hepatic Failure
- Diabetic Ketoacidosis
- Acute Suprarenal Failure

20 Chapter

Temperature Abnormalities

Hypothermia

Causes

Cardiopulmonary arrest
Acute critical illnesses
Drowning and near-drowning

Grades and effects

Mild: 35-36°C (±)
Moderate: 32- 35°C (+)
Severe: 28-32° C (++)
Profound: below 28° C (+++)

Management

External rewarming
Internal (core) rewarming

Fever

Causes

Infections, inflammations
Dehydration, drugs
Tissue injury (burns, infarction)

Grades and effects

Mild: 37.8-38.4°C (±)
Moderate: 38.5-39.4°C (+)
High: 39.5- 41. 0°C (++)
Hyperpyrexia: Above 41.0°C (+++)

Management

Antipyretics and hydration
External and internal cooling

The body temperature is controlled within a normal narrow range (36-37.5°C) by the internal thermostat of the hypothalamus, which controls the balance between heat production and heat loss. **Heat production** occurs through metabolic activities of tissues, skeletal muscular contractions and hormonal stimulation of metabolic activities by thyroxin and catecholamines. **Heat loss**, on the other hand, occurs through radiation (60%), evaporation (25%), convection (12%) and conduction (3%).

- With **hypothermia**, the hypothalamic thermostat controls the body temperature through increasing heat production (release of thyroxin and catecholamines, increase in muscle tone and shivering) and decreasing heat loss (vasoconstriction, abolishing sweating).
- With **fever or hyperthermia**, the hypothalamic thermostat controls the body temperature by increasing heat loss (vasodilatation of peripheral vessels, stimulation of sweating) and decreasing heat production.
- The hypothalamic thermoregulatory mechanism is effective within limits and thermoregulatory failure occurs in severe and extreme cases.

HYPOTHERMIA

Infants and young children are particularly more susceptible to hypothermia because of the relatively larger surface area and the scanty subcutaneous fat.

Causes

In pediatric emergency medicine, hypothermia can occur in three groups of patients. During **cardiopulmonary resuscitation**, hypothermia commonly occurs if measures to keep the body temperature are not considered. Many patients who were normothermic at the moment of arrest become hypothermic and resistant to resuscitation. Moreover, the diagnosis of brain death cannot be made if core temperature is below 32°C because severe hypothermia produces a picture similar to clinical death. Hypothermia is also common with several acute critical illnesses. Acute respiratory failure, acute congestive heart failure, shock, deep coma, hypoglycemia and fulminant sepsis are the main causes. In drowning and near-drowning, hypothermia is one of the major four events that occur with submersion injury (anoxic-ischemic injury, hypothermia, pulmonary injury and fluid overload).

Grades and effects

According to the degree of lowering of body temperature, hypothermia is divided into four grades.

Grades of hypothermia

Mild hypothermia: Core temperature between 35-36°C.

Moderate hypothermia: Core temperature between 32-35°C.

Severe hypothermia: Core temperature between 28-32°C.

Profound hypothermia: Core temperature below 28°C.

- A low-grade thermometer is needed for measurements.

Hypothermia is a serious potentially fatal condition with several adverse effects on most organ systems. The degree of dysfunction of body organs depends on the severity and duration of hypothermia.

Effects of hypothermia

Mild hypothermia

No serious effects. Shivering and peripheral vasoconstriction are the main findings.

Moderate to severe hypothermia

Respiratory: Hypoventilation, central respiratory depression, ARDS, apnea.

Cardiovascular: Bradycardia, impaired myocardial contractility, hypotension, cardiac arrhythmias (asystole or ventricular fibrillation).

Neurologic: Reduced cerebral blood flow, drowsiness, confusion, coma.

Metabolic: Mixed acidosis (due to hypoxemia and hypoventilation).

Electrolyte disturbance (hypokalemia and hypomagnesemia may occur).

Hypoglycemia (glycogen depletion) or hyperglycemia (decreased utilization).

Depressed renal and hepatic functions.

Hematologic: Thrombocytopenia, platelet dysfunction, DIC.

Increased susceptibility to infection (impaired neutrophil function).

Profound hypothermia

False appearance of death (deep coma, unresponsiveness, apnea).

Pulse, if present, cannot be felt due to extreme bradycardia and vasoconstriction.

MANAGEMENT

Ideally, hypothermia should be avoided during cardiopulmonary resuscitation and in patients with acute critical illness. External rewarming is usually sufficient if core temperature is above 32°C. Rewarming is better made at a rate of 0.5 - 1.0°C per hour and should be discontinued when core temperature reaches 35°C to avoid overheating. Internal (core) rewarming is indicated if core temperature is below 32°C.

Rewarming in hypothermia

External rewarming (with core temperature above 32°C)

- Remove cold, wet clothes.
- Wrap the patient in warm blankets.
- Use preheated incubators for newborns and young infants.
- Use overhead radiant warmer for infants and children.
- Infrared heating lamp (with appropriate distance from the patient).
- Immersion in a warm bath at 40°C for 10 minutes.

Internal or core rewarming (with core temperature below 32°C)

- Warm I.V. fluids at 37°C.
- Warm humidified oxygen at 42°C.
- Gastric irrigation with warmed saline at 42°C.
- Bladder irrigation with warmed saline at 42°C.
- Peritoneal irrigation with K-free dialysate at 42°C. Use 20 ml/kg cycled every 15 minutes.
- Pleural or pericardial irrigation with warmed saline at 42°C.

- Rewarming shock may occur due to hypovolemia secondary to peripheral vasodilatation.
- Ventricular fibrillation may occur in patients recovering from severe hypothermia.
- Fluid overload may occur with I.V. fluids and repeated irrigation.

FEVER

Fever is an elevation of body temperature above normal. The normal rectal temperature in children is 36.5-37.8°C. Normal oral temperature is a half-degree lower than the rectal temperature. Normal skin temperature is two degrees lower.

Grades and effects

Grades of fever in children

- Mild fever:** Rectal temperature of 37.8-38.4°C.
- Moderate fever:** Rectal temperature of 38.5-39.4°C.
- High fever:** Rectal temperature of 39.5-41.0°C.
- Hyperpyrexia:** Rectal temperature above 41.0°C.

The common pathway of most causes of fever is the production of endogenous pyrogens, which raise the hypothalamic temperature set point resulting in increased heat production and fever.

The term "**hyperthermia**" is an elevation of body temperature due to external heating (i.e. high environmental temperature). High incubator temperature in newborns and heat stroke in children are examples. Therefore, hyperthermia is not a true fever because the elevation of body temperature is against the body desire. In case of fever, the patient feels cold and the extremities may also be cold while in hyperthermia the patient feels hot and extremities are also hot.

The effects of fever depend on the degree and the causative disease. Most children can tolerate *mild to moderate fever* without any serious effects. Heart rate, respiratory rate and oxygen consumption proportionately increase according to the degree of fever. *High fever* may lead to febrile convulsions in susceptible children and may precipitate an epileptic fit in epileptic children. *Hyperpyrexia* is a serious condition, which causes cardiovascular collapse (shock) and direct cellular damage especially of CNS and muscles. Generalized rhabdomyolysis and muscular spasms may occur. Coma appears at 43°C and death may occur within several hours.

Causes

Infections are by far the most common cause of short febrile illness in children. It is clinically useful to classify infections into focal infections (simple infections, serious infections) and fever without a focus or simple fever (viremia, bacteremia and septicemia). Accurate history and meticulous examination of all systems is essential for accurate diagnosis. **High fever or hyperpyrexia** should suggest serious bacterial infection especially serious focal infections or septicemia. Clinical examination and investigations should be directed to identify these infections (see serious infections).

Serious bacterial infections associated with high fever or hyperpyrexia

Serious focal infections

Bacterial meningitis: Disturbed consciousness, convulsions, meningeal irritation.

Pneumonia: Respiratory distress, focal chest signs.

Purulent pericarditis: Chest pain, dyspnea, tachycardia, cardiac tamponade.

Pyelonephritis: Loin tenderness or a swelling.

Peritonitis: Abdominal distension and generalized tenderness.

Osteomyelitis or arthritis: Focal tenderness, swelling and limitation of movements.

Fulminant sepsis or septicemia

Clinical manifestations may pass into 5 stages (see septic shock).

- I. Sepsis and systemic inflammatory response syndrome (SIRS): Fever or hypothermia, tachycardia and tachypnea, bandemia or leukocytosis.
- II. Severe sepsis: Sepsis + mental changes, oliguria, acidosis or hypoxemia.
- III. Early septic shock: Severe sepsis + responsive hypotension.
- IV. Late septic shock: Severe sepsis + refractory hypotension or poor perfusion.
- V. Multiple organ system failure (MOSF).

- Manifestations of multiple organ system failure include one or more of the following five (DIC, ARDS, acute renal failure, acute hepatic failure, acute CNS dysfunction).

Other causes of fever should also be considered especially dehydration, drugs (as atropine), tissue damage (burns, infarction) and acute conditions causing hypothalamic dysfunction (as massive intracranial hemorrhage or CNS infections).

MANAGEMENT

Lowering of the elevated body temperature can be made by several methods. Mild fever requires no therapy.

1. **Antipyretics:** Oral antipyretics as *paracetamol* (10-15 mg/kg/dose, every 4-6 hours) or ibuprofen (10-15 mg/kg/dose, every 4-6 hours) can be used in moderate to high fevers. The rectal forms (suppositories) of these drugs can be considered in patients with high fever and tendency to vomiting. Parenteral acetylsalicylic acid (Aspegic injectable, 500 mg/5 ml) can be used in patients with fever above 40.5°C in a dose of 10-15 mg/kg/dose, I.V. or I.M. Other antipyretic drugs can also be used.
2. **External cooling:** External cooling through tepid sponges with tap water is a useful measure in patients with high fever or hyperpyrexia. Cold or iced-water sponges should be avoided as it induces shivering and continued heat production. Similarly, alcohol sponges cause peripheral vasoconstriction and decreased heat loss. Running tap water over limbs is probably more effective due to increased heat loss through conduction (conductivity in running water is better).
3. **Internal or core cooling:** These measures can be used in patients with hyperpyrexia not responding to I.V. antipyretics and tepid sponges. These measures include cold I.V. fluids, iced saline gastric irrigation, iced saline enema and iced saline bladder irrigation.
4. **Good hydration:** Excess fluid intake is an important simple measure. In patients receiving I.V. fluids, the maintenance requirements are increased 10% for each degree rise of body temperature.

Specific treatment of the causative disease is equally important. Appropriate parenteral antibiotic therapy should be used in serious bacterial infections.

21

Chapter

Water Imbalance

Dehydration

Causes

Fasting dehydration
Diarrheal dehydration
Polyuric dehydration

Diagnosis

Weight loss
Other signs

Management

Rehydration
Treatment of complications
Specific treatment

Fluid Overload

Causes

System failure
Near drowning
Iatrogenic water intoxication

Diagnosis

Weight gain
Other signs

Management

Fluid restriction
Diuretics
Specific treatment

The total body water (TBW) is controlled by a hypothalamic center, which regulates the balance between water intake and water excretion. This regulation depends mainly on plasma osmolarity, which should remain almost constant at 285-295 mOsm/kg H₂O. Water intake is mainly regulated by thirst (desire to drink water), which is very sensitive to minor changes in plasma osmolarity (1-2% increase in plasma osmolarity stimulates thirst). On the other hand, water excretion is mainly regulated by the urinary water excretion, which depends on the release of antidiuretic hormone (ADH). Other sources of water excretion as stool water losses and insensible water losses (evaporated water losses from the lungs and skin) play a minor role in water excretion.

- With dehydration, plasma osmolarity increases, and this stimulates thirst (to increase water intake) and stimulates the release of ADH (to decrease urinary water excretion).
- With fluid overload, plasma osmolarity decreases and this inhibits thirst (to decrease water intake) and inhibits the release of ADH (to increase urinary water excretion).
- Plasma osmolarity is also influenced by the concentration of solute particles in plasma.

DEHYDRATION

Dehydration is a loss of body fluids, mainly from the extracellular compartments. It is a common and serious problem especially in infants and young children for two

reasons— (1) severe gastroenteritis with persistent vomiting (fasting dehydration) and severe diarrhea (diarrheal dehydration) is much commoner in this age group, (2) loss of extracellular fluids is much easier in this age group because it accounts for 30% of body weight compared to only 15% in adults.

Water content and water distribution in infants compared to adults

Age	Water content	Water distribution		
		Cellular	Extracellular	Vascular
Infant	75%	40%	30 %	5%
Adult	60%	40%	15%	5%

CAUSES

The most common 2 causes of dehydration in pediatric age group are severe gastroenteritis in infants and diabetic ketoacidosis in children. Other causes include severe vomiting, prolonged fasting and urinary disorders characterized by severe polyuria as diabetes insipidus.

Causes of dehydration according to the mechanism

Fasting dehydration: Severe persistent vomiting, prolonged fasting.

Diarrheal dehydration: Severe gastroenteritis, short bowel syndrome.

Polyuric dehydration: Diabetic ketoacidosis, diabetes insipidus.

DIAGNOSIS

Clinical signs of dehydration include depressed fontanel, sunken eyes, dry tongue, lost skin turgor (or elasticity) over the abdomen and acute weight loss. Diagnosis should include the degree and type of dehydration and associated complications

- Degree of dehydration:** Dehydration is assessed clinically as mild, moderate or severe according to the severity of signs and the degree of weight loss (mild: 4%, moderate: 8% and severe: 12%). Although the degree of weight loss is the most accurate method, it cannot be applied in practice because the accurate weight before illness is usually unknown. However, accurate weighing of the patient is very important because weight gain is the most reliable sign of effective rehydration.

Degrees of dehydration

	Mild	Moderate	Severe
Weight loss	4%	8%	12%
Sunken eyes	Mild	Moderate	Severe
Dry tongue	±	dry	very dry
Skin elasticity	Pinch retracts immediately	Pinch retracts slowly	Pinch retracts very slowly
Consciousness	Normal	Lethargy	Coma
Shock	Absent	May present	Present
Estimated fluid loss	40 ml/kg	80 ml/kg	120 ml/kg

2. Types of dehydration: Dehydration can be isonatremic, hypernatremic or hyponatremic according to the level of serum sodium.

	Types of dehydration		
	Isonatremic (isotonic)	Hypernatremic (hypertonic)	Hyponatremic (hypotonic)
Incidence	75%	15%	10 %
Water/electrolyte losses	Water loss + + Na loss + +	Water loss + + + Na loss +	Water loss + Na loss + + +
Tongue	Dry	Very dry	Moist
Skin turgor	Lost	Normal	Marked loss
Consciousness	Lethargy	Irritability	Coma
Serum sodium	Normal (135 - 140 mEq/liter)	High (Above 150 mEq/liter)	Low (Below 130 mEq/liter)

3. Complications: The most common complications of severe dehydration are hypovolemic shock, acute renal failure, metabolic acidosis (diarrhea, diabetic ketoacidosis) or metabolic alkalosis (severe vomiting) and electrolyte disturbances (hyponatremia or hypernatremia, hypocalcemia, hypokalemia). DIC may also occur.

MANAGEMENT

1. Correction of dehydration: It depends on the degree and type of dehydration, cause of dehydration and the presence or absence of complications.

a. Fasting dehydration: Patients with severe persistent vomiting and fasting dehydration should be hospitalized and receive I.V. fluid therapy. Initial shock therapy is preferably made with normal saline (20 ml/kg, I.V. over 10-15 minutes) to compensate for acid loss and to prevent alkalosis. Deficit therapy is calculated according to the degree of dehydration and is given over 8 hours. Maintenance therapy then follows and is given over the next 15-16 hours. Hypokalemia and continued losses should be considered.

b. Diarrheal dehydration: Treatment of infants with severe gastroenteritis and dehydration depends mainly on the severity of dehydration and presence or absence of vomiting. Home management is indicated in mild dehydration not associated with significant vomiting. Oral rehydration can be made with oral rehydration solution (150 ml/kg/day). Hospital management is indicated in moderate to severe dehydration or presence of complications as shock, renal failure, metabolic acidosis or convulsions.

- Continuous nasogastric drip of oral rehydration solution may be initially tried in emergency room in patients with mild dehydration and history of severe vomiting. It is given in amount of 150 ml/kg/day (6 ml/kg/hour or 2 drops/kg/minute). Persistent vomiting or weight loss is an indication of I.V. fluid therapy.
- I.V. fluid therapy is indicated in patients with moderate to severe dehydration and in those with complications (see severe gastroenteritis).

- c. **Diabetic ketoacidosis:** Children with an episode of diabetic ketoacidosis should be hospitalized, preferably in an intensive care unit. I.V. fluid therapy is essential for correction of shock, metabolic acidosis and dehydration (for details of therapy, see diabetic ketoacidosis).
2. **Specific treatment:** Parenteral antiemetics (as metoclopramide, 0.5-1.0 mg/kg/day, in divided doses) may be used in patients with severe vomiting. Parenteral antibiotics are indicated in severe bacterial gastroenteritis with clinical manifestations suggesting septicemia. Insulin therapy is essential in diabetic ketoacidosis.

FLUID OVERLOAD

Fluid overload and hypervolemia occurs in several situations. *System failure* as acute congestive heart failure, acute renal failure and acute hepatic failure are the most common. It may also occur with inappropriate secretion of antidiuretic hormone. In near-drowning, large quantity of water is swallowed leading to fluid overload, cerebral edema and convulsions. *Iatrogenic causes* of volume overload include over-infusion of I.V. fluids.

DIAGNOSIS

Clinical manifestations of volume overload and hypervolemia include acute weight gain, peripheral edema, hypertension, liver enlargement, fine basal crepitations and may be heart failure and pulmonary edema. Central venous pressure (CVP) is elevated (above 7-10 cm H₂O) and dilutional hyponatremia and hypocalcemia are usually present. In case of water intoxication (as in near-drowning or excessive hypotonic I.V. fluids), brain edema occurs leading to coma and convulsions.

Specific clinical manifestations related to the causative illness should be observed. Accurate history, proper clinical evaluation and relevant investigations can easily guide towards the correct diagnosis.

MANAGEMENT

Treatment of fluid overload and hypervolemia includes the following:

1. **Fluid restriction:** The total fluid intake should be reduced to 60-70% of daily requirements (2-3 ml/kg/hour).
2. **Diuretics:** Furosemide is given I.V. in a dose of 1-2 mg/kg and can be repeated. Mannitol can also be given in patients with water intoxication and brain edema to act as a cellular dehydrating measure (see increased intracranial pressure).
3. **Specific treatment:** Peritoneal dialysis is indicated in severe acute renal failure not responding to conservative measures. Heart failure and hepatic failure are treated with several specific measures. Water intoxication with brain edema and increased ICP is managed with mechanical hyperventilation to reduce cerebral blood volume and intracranial pressure.

22

Chapter

Acid-base Disorders

Acidosis

Metabolic acidosis

Causes

Excess acids (diseases)
Base loss (diarrhea)

Blood gases

Low pH (acidemia)
Low bicarbonate
± Low PCO₂ (compensatory)

Respiratory acidosis

Causes

Hypoventilation

Blood gases

Low pH (acidemia)
High PCO₂
± High bicarbonate (compensatory)

Alkalosis

Metabolic alkalosis

Causes

Excess base (iatrogenic)
Acid loss (vomiting)

Blood gases

High pH (alkalemia)
High bicarbonate
± high PCO₂ (compensatory)

Respiratory alkalosis

Causes

Hyperventilation

Blood gases

High pH (alkalemia)
Low PCO₂
± Low bicarbonate (compensatory)

- **Mixed disorders** also occur. The most common examples are:
- * Metabolic and respiratory acidosis in severe respiratory failure (pH is very low)
- * Metabolic acidosis and respiratory alkalosis in hepatic failure (pH is near normal)

Acid-base balance is the balance of the *free hydrogen ion concentration* in the body, which is kept constant by buffering systems, pulmonary mechanism and renal mechanism. pH is the negative logarithm of the hydrogen ion concentration. Acid is a hydrogen ion donor and base is a hydrogen ion acceptor. In the blood, the concentration of free hydrogen ion is 40 mEq/litre, which is equivalent to pH of 7.4. The bicarbonate-carbonic acid system is the main buffering system in the blood and extracellular fluids ($\text{H}^+ + \text{HCO}_3 = \text{H}_2\text{OCO}_3 = \text{CO}_2 + \text{H}_2\text{O}$). The addition of hydrogen ions derives this equation to right on the expense of bicarbonate. It is important to note that the pH does not depend on the absolute level of bicarbonate and PCO₂ but on the ratio of two concentrations ($\text{pH} = 6.1 + \text{Log} (\text{bicarbonate}/\text{carbonic acid})$).

- In normal conditions, the concentration of free hydrogen ion (or pH) is kept constant by different intracellular and extracellular **buffering systems**, and by renal excretion of excess hydrogen ions (through reabsorption of bicarbonate in proximal tubules and excretion of acids and ammonia in distal tubules).

- In acid-base disorders, the buffering systems are unable to maintain a normal pH and their action should be supplemented by 2 other mechanisms; **initial compensation** and **ultimate correction**. In metabolic disorders (acidosis or alkalosis), initial compensation occurs through the pulmonary mechanism (hyperventilation or hypoventilation, respectively) and ultimate correction occurs through the renal mechanism. On the other hand, in respiratory disorders (acidosis or alkalosis), initial compensation occurs through the kidneys (bicarbonate retention or bicarbonate loss, respectively) and ultimate correction occurs by the pulmonary mechanism. It is important to remember that compensation can never return pH to normal value.

Blood gas changes in primary or simple acid-base disorders

Disorder	pH	Initial effect	Compensation	Correction
Metabolic acidosis	Low	Low bicarbonate	Low PCO ₂	Renal
Metabolic alkalosis	High	High bicarbonate	High PCO ₂	Renal
Respiratory acidosis	Low	High PCO ₂	High bicarbonate	Respiratory
Respiratory alkalosis	High	Low PCO ₂	Low bicarbonate	Respiratory

- The expected compensation** varies according to the primary disorder.

Metabolic acidosis: Every 1 mEq/liter decrease in HCO₃ causes 1 mmHg decrease in PCO₂

Metabolic alkalosis: Every 1 mEq/liter increase in HCO₃ causes 0.7 mmHg increase in PCO₂

Respiratory acidosis: Every 1 mmHg increase in PCO₂ causes 0.35 mEq increase in HCO₃

Respiratory alkalosis: Every 1 mmHg increase in PCO₂ causes 0.5 mEq increase in HCO₃

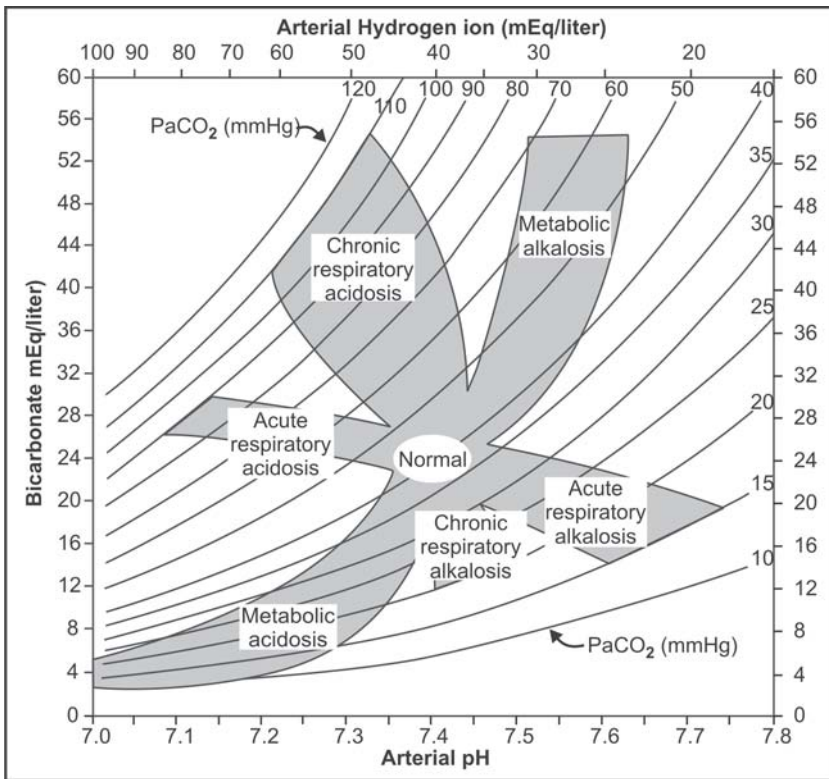
BLOOD GAS ANALYSIS

Arterial or arterialized (capillary) samples can be used to assess oxygenation, ventilation and acid-base status. Venous samples can be used to assess ventilation and acid-base status but are not reliable to assess oxygenation because of the marked difference between arterial and venous PO₂ (see respiratory distress).

Important parameters in diagnosis of acid-base disorders

- Type:** Acidosis or alkalosis (by pH).
 - Cause:** Metabolic or respiratory (by PCO₂ and bicarbonate).
 - Response:** Uncompensated or compensated and uncorrected or corrected.
 - Duration:** Acute (less than 48 hours) or chronic (more than 48 hours).
 - Form:** Simple (one disorder) or mixed.
 - Severity:** Mild, moderate, severe or profound.
- A nomogram** for clinical assessment of simple acid-base disorders can be used to guide diagnosis. It depends on the 3 main components of acid-base balance (pH, PCO₂ and bicarbonate).
 - Mixed disorder** is considered if the compensatory response falls outside the expected value (see above). Mixed metabolic and respiratory acidosis (very low pH, near normal PCO₂ and bicarbonate) is the most common. It occurs in severe respiratory failure (metabolic due to hypoxemia and respiratory due to hypoventilation). Metabolic acidosis and respiratory alkalosis in patients with acute hepatic failure is another example. In this case, pH is near normal while PCO₂ and bicarbonate are reduced.
 - Blood gas analysis should be correlated with the clinical condition of the patient and the given treatment.

Nomogram for diagnosis of simple acid-base disorders
(Depending on pH, PaCO₂ and serum bicarbonate)



- In metabolic disorders, pH and bicarbonate are affected.
- In acute respiratory disorders, PCO₂ and pH are affected.
- In chronic respiratory disorders, PCO₂ is affected and pH is near normal.

METABOLIC ACIDOSIS

Metabolic acidosis is a common and serious acid-base disturbance, which results from either excess acid or base loss (see below). In both conditions, the pH is low and serum bicarbonate is also low. The low serum bicarbonate results from the *buffering effect* of bicarbonate-carbonic acid system, which is shifted to the right.



Initial compensation occurs through hyperventilation (deep rapid respiration or Kussmaul breathing) to wash the accumulated CO₂ out. Ultimate correction occurs through the renal mechanism (increased hydrogen ion excretion and increased bicarbonate reabsorption).

Causes of acute metabolic acidosis**Excess acids**

Cardiopulmonary arrest (anaerobic metabolism and release of lactic acid).
 Severe hypoxemia (anaerobic metabolism and release of lactic acid).
 Established and advanced shock (hypoperfusion with overproduction of lactic acid).
 Fulminant sepsis (overproduction of lactic acid).
 Acute renal failure (underexcretion of acids).
 Diabetic ketoacidosis (overproduction of ketoacids).
 Salicylate poisoning (exogenous acids).
 Acute-on-chronic: Aminoacidopathies, chronic renal failure, glycogenosis type I.

Bicarbonate loss

Severe diarrhea (due to intestinal loss).
 Acute episode of renal tubular acidosis (due to renal loss).

- **Anion gap** can be used to differentiate between these 2 groups. Elevated anion gap indicates excess acids and normal anion gap indicates bicarbonate loss.
 $\text{Anion gap} = (\text{Na}^+ + \text{K}) - (\text{Cl} + \text{HCO}_3) = 12 \text{ mEq/liter}$. A range of 8-16 mEq/liter is considered normal.

DIAGNOSIS

The possibility of metabolic acidosis should be considered in all clinical situations associated with acidosis (see above). In mild cases, the clinical manifestations of the causative disease are the main findings. Moderate to severe acidosis is detected clinically by the **deep rapid respiration** (**acidotic breathing** or Kussmaul breathing) which occurs due to compensatory hyperventilation. With severe or profound acidosis, **disturbed consciousness** (coma) and serious cardiovascular effects occur. These effects include **decreased myocardial contractility** (**cardiogenic shock**), lowered threshold to serious **arrhythmias** (asystole, ventricular fibrillation), decreased systemic vascular resistance, increased pulmonary vascular resistance (due to pulmonary vasoconstriction) and unresponsiveness to catecholamines.

Grades of metabolic acidosis

Grade	Clinical findings	pH	Bicarbonate
Mild	Not detected clinically	Below 7.3	Below 16 mEq/L
Moderate	Deep rapid respiration	Below 7.2	Below 13 mEq/L
Severe	Coma, shock, arrhythmias	Below 7.1	Below 10 mEq/L
Profound	Death	Below 7.0	Below 7 mEq/L.

MANAGEMENT

Treatment of metabolic acidosis includes correction of acidosis with bicarbonate therapy and specific treatment of the cause.

1. **Correction of acidosis:** Treatment of metabolic acidosis with **sodium bicarbonate** is indicated in moderate, severe and profound acidosis to avoid the adverse CNS and cardiovascular effects. It can be made by any of two methods:

- a. Empirical correction:** It is indicated in emergency situations and when facilities for blood gas analysis are not immediately available. The dose is **2 mEq/kg, I.V. over 10 minutes**. This dose is equivalent to 4 ml/kg of sodium bicarbonate 5% solution or 2 ml/kg of sodium bicarbonate 8.4% solution. Each 1 ml/kg of the 5% solution will raise the serum bicarbonate level by about 1 mEq, while each 1 ml/kg of the 8.4% solution will raise the serum bicarbonate level by about 2 mEq. The dose may be repeated in severe cases but overcorrection and/or hypernatremia are potential risks.
- b. Accurate correction:** It depends on the serum bicarbonate level. The dose of sodium bicarbonate in mEq/kg is calculated from the following formula:

$$\text{NaHCO}_3 \text{ (mEq/kg)} = 0.5 (\text{desired bicarbonate} - \text{actual bicarbonate})$$
 If the desired bicarbonate is 16 and actual bicarbonate is 10, the dose of bicarbonate in mEq/kg = $0.5 (16 - 10) = 0.5 \times 6 = 3 \text{ mEq/kg}$. This dose is equivalent to 6 ml/kg of the 5% solution or 3 ml/kg of the 8.4% solution. Full correction should be avoided because the compensatory mechanisms of the body play a role in the process of correction and iatrogenic alkalosis may occur. Blood gas analysis should be repeated after 15 minutes. Sodium bicarbonate therapy can be repeated every 10-15 minutes until the pH is above 7.25 and bicarbonate above 15 mEq/liter. Failure of response to sodium bicarbonate therapy should suggest persistent severe disorder especially severe hypoxemia and/or advanced shock.

Adverse effects of sodium bicarbonate therapy

Metabolic alkalosis and impaired release of oxygen from hemoglobin to tissues.
 Hypernatremia and hyperosmolality
 Hypercapnic acidosis and impaired myocardial contractility.
 Paradoxical intracellular acidosis due to rapid intracellular entry of CO_2 .

- 2. Specific treatment of the cause:** Urgent and specific treatment of the causative disease is equally important. Severe hypoxemia should be corrected with oxygen therapy and may be mechanical ventilation. Established and advanced shock necessitates urgent cardiovascular support with volume expanders. I.V. fluid therapy and insulin therapy are the main lines of treatment in patients with diabetic ketoacidosis. Acute renal failure is treated with volume expansion, diuretics and low dose dopamine infusion. In patients with gastroenteritis and dehydration, shock therapy with I.V. Ringers lactate usually corrects the acidosis through correction of shock, improvement of renal circulation and the lactate content, which changes to bicarbonate.

METABOLIC ALKALOSIS

Metabolic alkalosis results from either base excess (usually iatrogenic due to excess use of sodium bicarbonate) or acid loss (as in severe persistent vomiting or prolonged gastric aspiration).

The pH is high and serum bicarbonate is also high. Respiratory compensation with hypoventilation is of limited effect and some rise of PCO_2 may occur. Renal correction is made by increased bicarbonate excretion.

The clinical manifestations are not characteristic. Muscular spasms or tetany may occur if ionized calcium is reduced by the alkalosis. Coma may occur in severe cases. Associated hypokalemia (due to increased urinary losses) and hypochloremia are usually present.

Treatment of metabolic alkalosis includes the following:

1. Use of a rebreathing bag to cause CO_2 retention to enhance compensation.
2. Calcium gluconate 10% (1 ml/kg, slow I.V.) in patients with tetany.
3. In patients with persistent vomiting, volume expansion with I.V. normal saline (20 ml/kg) will enhance correction.
4. Associated hypovolemia and/or hypokalemia should be corrected. Persistence of these factors increases renal reabsorption of bicarbonate and makes the alkalosis more resistant to therapy.

RESPIRATORY ACIDOSIS

Respiratory acidosis is a sign of hypoventilation because PCO_2 is inversely proportionate to ventilation. Hypoventilation can be acute or chronic and it is mainly characterized by CO_2 retention. According to the degree of PCO_2 elevation, hypoventilation can be divided as mild (45 - 50 mm Hg), moderate (50 - 60 mm Hg) or severe (above 60 mm Hg).

Causes of hypoventilation (type II respiratory failure)

Acute hypoventilation

- CNS respiratory depression (with coma, CNS depressant drugs).
- Respiratory muscle paralysis: With poliomyelitis, Guillain Barre syndrome.
- Respiratory muscle fatigue: With severe persistent respiratory distress.

Chronic hypoventilation

- Chronic obstructive airway disease: With asthma.
- Chronic neuromuscular respiratory weakness: With muscular dystrophies.
- Chronic use of sedatives.

Respiratory acidosis can be acute or chronic:

- **Acute respiratory acidosis** occurs with acute hypoventilation. It is characterized by high PCO_2 , low pH and normal bicarbonate level. The acute elevation of PCO_2 above 60 mm Hg results in disturbed consciousness (CO_2 narcosis).
- **Chronic respiratory acidosis** occurs with chronic hypoventilation and it also occurs with acute hypoventilation persisting for more than 48 hours. It is characterized by high PCO_2 , near normal pH and elevated bicarbonate (due to renal compensation and increased bicarbonate reabsorption). The elevation of PCO_2 above 60 mm Hg is not associated with disturbed consciousness because of the slow rise and the near normal pH (see the nomogram of acid-base disorders and observe the difference between acute and chronic respiratory acidosis).

Management of hypoventilation includes the nonspecific respiratory support (oxygen therapy, chest physiotherapy and suctioning and positive pressure support) and treatment of the causative disease. For details of therapy, see respiratory distress (lung failure) and hypoventilation (pump failure).

RESPIRATORY ALKALOSIS

Respiratory alkalosis is a sign of hyperventilation because PCO_2 is inversely proportionate to ventilation. Hyperventilation can be compensatory, therapeutic or iatrogenic (see below). It is mainly characterized by increased minute ventilation (tidal volume \times respiratory rate), which manifests clinically as deep rapid respiration. According to the degree of CO_2 lowering, hyperventilation can be divided into mild (25-30 mm Hg), moderate (20-25 mm Hg) and severe (15-20 mm Hg). As PCO_2 is directly proportionate to cerebral blood flow, moderate to severe hyperventilation is very serious and it leads to severe cerebral ischemia and brain damage.

Causes of hyperventilation

Compensatory hyperventilation

- Severe airway obstruction or severe lung disease.
- Severe acute metabolic acidosis.
- Increased intracranial pressure (central neurogenic hyperventilation).
- Drug intoxication especially early salicylate poisoning.

Therapeutic hyperventilation

- Mechanical hyperventilation in acute pulmonary hypertension.
- Mechanical hyperventilation in markedly increased intracranial pressure.

Iatrogenic hyperventilation

- Mechanical ventilation with high settings (increased tidal volume and/or rate).

Respiratory alkalosis can be acute or chronic.

- **Acute respiratory alkalosis** is characterized by low PCO_2 and high pH. Severe alkalosis can lead to coma.
- **Chronic respiratory alkalosis** occurs within 2 days due to renal compensation. It is characterized by low PCO_2 , low bicarbonate and near normal pH (see nomogram of acid-base disorders).

23 Chapter

Electrolyte Disorders

Hypoelectrolemia

Hyponatremia
Hypokalemia
Hypocalcemia
Hypomagnesemia

Hyperelectrolemia

Hypernatremia
Hyperkalemia
Hypercalcemia
Hypermagnesemia

The electrolyte concentration in extracellular and intracellular body fluids is different, but in each compartment, the total concentration of cations and anions is the same (cation-anion balance). In the extracellular fluids (plasma, interstitial fluids), the total concentration of anions or cations is around 150 mEq/liter while in intracellular fluids, the total concentration is much higher (200 mEq/liter).

Cation-anion balance in body fluid compartment

Extracellular (plasma, interstitial)

Cations (+)

150 mEq/L

Na (92%)
K (3%)
Ca (3%)
Mg (2%)

Anions (—)

150 mEq/L

Cl (70%)
HCO₃ (16%)
Proteins (10%)
P04/Org. (4%)

Intracellular

Cations (+)

200 mEq/L

K (78%)
Mg (12%)
Na (7%)
Ca (3%)

Anions (—)

200 mEq/L

PO₄/Org. (56%)
Proteins (37%)
HCO₃ (5%)
Cl (2%)

- Sodium is the principal extracellular cation (92%)
- Potassium is the principal intracellular cation (78%)
- Chloride is the principal extracellular anion (70%)
- Phosphate (PO₄), organic acids (Org.), proteins are the main intracellular anions (93%).

In this chapter, *only the electrolyte disorders* of cations are discussed. Chloride disorders are parallel to sodium disorders. Hypochloremia and hyperchloremia are usually associated with comparable degrees of hyponatremia and hypernatremia. Disorders of bicarbonate are dealt with in the chapter of acid-base disorders. Metabolic acidosis is associated with low bicarbonate level and metabolic alkalosis is associated with high bicarbonate level.

SODIUM DISORDERS

Sodium is the principal extracellular cation (92%) and it is the main responsible electrolyte for maintenance of intravascular and interstitial volumes. 43% of total body sodium is present in bones and 29% of them are nonexchangeable. Another 40% of total body sodium is present in interstitial fluids (29%) and plasma (11%).

Sodium disorders result from decreased or increased total body sodium. It is important to note that the serum sodium concentration does not necessarily reflect the status of total body sodium content. Both hyponatremia and hypernatremia are common serious problems.

Causes of sodium disorders

Hyponatremia

Hyponatremic dehydration
Fresh-water near-drowning
Volume overload (dilutional)
Diuretics
Iatrogenic hyponatremia

Hypernatremia

Hypernatremic dehydration
Salt-water near-drowning
Diabetes mellitus
Diabetes insipidus
Iatrogenic hypernatremia

Hyponatremia

Hyponatremia is defined as a serum sodium concentration below 130 mEq/liter. According to the degree of lowering of serum sodium, hyponatremia can be classified as mild (120-130), moderate (110-120) and severe (below 110 mEq/liter).

Hyponatremic dehydration and excessive use of diuretics are the commonest causes. Volume overload as in acute system failure (heart, liver, kidneys) or inappropriate secretion of ADH results in dilutional hyponatremia. Iatrogenic hyponatremia results from tap water enema or I.V. fluid therapy (hypotonic solutions or overinfusion).

Mild hyponatremia is asymptomatic. Moderate and severe hyponatremia (below 120 mEq/liter) are serious and usually lead to shock, coma and convulsions.

Treatment of asymptomatic hyponatremia can be made by increasing the saline content in I.V. fluids or by I.V. infusion of normal saline. Symptomatic hyponatremia necessitates therapy with hypertonic saline solution. Sodium chloride 3% solution is given by slow I.V. infusion in a dose, which raises serum sodium level to 125 mEq/liter. As each 1 ml/kg of this solution increases the serum sodium level by about 1 mEq/liter, the required dose in ml/kg = $125 - \text{actual serum sodium level}$. Two precautions are important:

1. The rate of infusion should not exceed 1 ml/minute.
2. The maximum dose/time is 10 ml/kg. In patients with serum sodium level below 115 mEq/liter, treatment should be made in multiple doses with 2 hours interval between each 2 doses. Serum sodium level should be measured after each dose.

Hypernatremia

Hypernatremia is defined as serum sodium concentration above 150 mEq/liter. According to the degree of rising of serum sodium level, hypernatremia can be classified as mild (150-160) moderate (160-170) and severe (above 170 mEq/liter).

Hypernatremic dehydration and iatrogenic hypernatremia are the commonest causes. Iatrogenic hypernatremia can result from excessive use of sodium bicarbonate during resuscitation, excessive use of hypertonic saline solution or hypernatremic enemas.

Mild hypernatremia is usually asymptomatic. Moderate and severe hypernatremia are serious and usually lead to hyperosmolarity and cytotoxic brain edema (increased ICP, coma, convulsions). Each 1 mEq/liter rise in serum sodium increases the plasma osmolarity by 2 mOsm/kg H₂O (normal plasma osmolarity is 285-295 mOsm/kg H₂O). Plasma osmolarity can be calculated from the following formula:

$$\text{Plasma osmolarity} = 2(\text{Na} + \text{K}) + (\text{glucose}/18) + (\text{urea}/3)$$

Causes and effects of hyperosmolarity

Causes

Hypernatremia: Each 1 mEq/liter rise increases osmolarity by 2 mOsm/kg H₂O.

Hyperglycemia: Each 100 mg/dl rise increases osmolarity by 5 mOsm/kg H₂O.

Uremia: Each 3 mg/dl rise increases osmolarity by 1 mOsm/kg H₂O.

Mannitol therapy (see increased intracranial pressure).

Effects

At 310 mOsm/kg H₂O, cytotoxic brain edema occurs.

At 340 mOsm/kg H₂O, renal failure occurs.

At 370 mOsm/kg H₂O, cellular disruption and systemic acidosis occurs.

The essential rule in treatment of hypernatremia (or any hyperosmolarity state) is the slow correction. Rapid expansion of extracellular fluids will aggravate brain edema because the reduced plasma osmolarity will cause more water entry into the cerebral cells. Convulsions occurring with hypernatremia can be controlled with anticonvulsants (see status epilepticus) and the rapid measures to reduce the elevated intracranial pressure. It is important to remember that convulsions may also occur due to associated hypocalcemia. Severe hypernatremia may necessitate peritoneal dialysis.

Treatment of hypernatremia and convulsions

Anticonvulsants

Give diazepam 0.5 mg/kg, I.V.

Correction of hypocalcemia

Give calcium gluconate 10%, 1 ml/kg slow I.V. over 10 minutes.

Rapid reduction of increased intracranial pressure

Head elevation 30° in neutral position to increase cerebral venous return.

Cellular dehydrating measures: Mannitol 20% solution (5-10 ml/kg, I.V.)

Mechanical hyperventilation to keep PaCO₂ between 25-30 mmHg.

- Sodium chloride solution 3% may be used as a cellular dehydrating measure to raise blood osmolarity and draw fluids out of brain cells. A single dose of 3-5 ml/kg, slow I.V. can be used.

POTASSIUM DISORDERS

Potassium is the principal intracellular cation (78%). 90% of total body potassium is intracellular and plasma content is only 0.4%. Potassium is important for muscle contraction, nerve impulse conduction, cardiac rhythm and intracellular osmotic pressure. The normal serum concentration is 4.0-5.5 mEq/liter. It is important to note that levels up to 6 mEq/liter in infants and 7 mEq/liter in newborns are normal.

Disorders of potassium results from decreased intake, decreased excretion or disorders that affect the intracellular shift of potassium either outside the cells (acidosis) or inside the cells (alkalosis). Hypokalemia is not a real emergency but hyperkalemia is a serious life-threatening condition.

Causes of potassium disorders

Hypokalemia

Alkalosis (shift inside cells)
Acute hepatic failure
Diabetic ketoacidosis
Diuretics, corticosteroids
Diarrhea cell lysis

Hyperkalemia

Acidosis (shift outside cells)
Acute renal failure
Acute suprenal failure
Iatrogenic

Hypokalemia

Hypokalemia is a serum potassium level below 3.0 mEq/liter. It is estimated that every 1 mEq/liter reduction in serum potassium level is equivalent to about 20-30% loss of total body potassium.

Clinical manifestations of hypokalemia include muscle weakness and abdominal distension (due to gastric dilatation or ileus). Extremely severe acute hypokalemia can lead to death through cardiac arrhythmia or respiratory muscle paralysis.

Treatment of hypokalemia can be oral or parenteral.

- **Oral potassium therapy** is indicated in diarrheal disorders and with drugs as diuretics or corticosteroids. Fresh orange or tomato juice contains about 50 mEq/liter of potassium. Oral potassium salts can also be given in a dose 2-4 mEq/kg/day. Available preparations are K-chlor syrup (4 mEq/5 ml) or Potassium syrup (10 mEq/5 ml).
- **I.V. potassium therapy** is indicated in acute hepatic failure, diabetic ketoacidosis and severe diarrheal dehydration. Potassium chloride solution 15 010 is used to raise the concentration of I.V. solution to 35-40 mEq/liter (Each 1 ml of this solution contains 2 mEq). Practically, 1.75-2.0 ml of this solution is added to each 100 ml of the glucose/saline mixture. It is important to remember that direct I.V. injection of potassium chloride solution is immediately fatal (see also acute hepatic failure and diabetic ketoacidosis).

Hyperkalemia

Hyperkalemia is a serum potassium level above 6.0 meq/liter (or above 7.0 meq/liter in newborns and infants). Acute renal failure is by far the commonest cause of hyperkalemia, which occurs due to decreased potassium excretion (90% of potassium is excreted by the kidneys) and associated metabolic acidosis (shift of intracellular potassium to plasma). Acute suprarenal failure, iatrogenic excess potassium intake and cell lysis (as hemolysis) are also associated with hyperkalemia.

Hyperkalemia is a life-threatening condition because it causes progressive heart block, which ends in asystole or ventricular fibrillation. ECG changes depend on the degree of hyperkalemia.

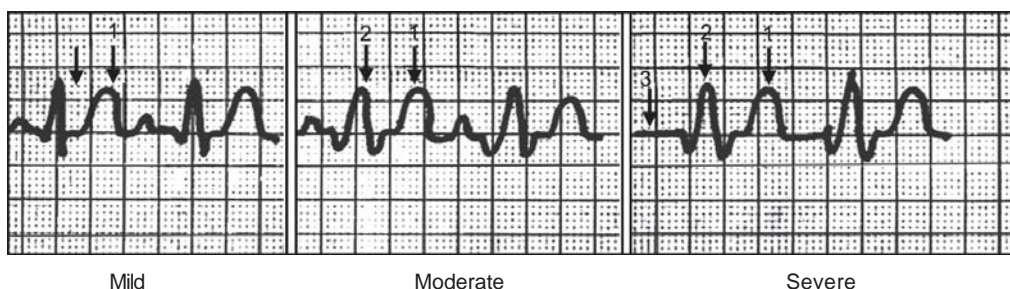
ECG signs of hyperkalemia

Mild hyperkalemia: Prolonged P-R interval and peaked or 'tented' T-wave

Moderate hyperkalemia: Prolonged P-R interval, peaked T-wave and wide QRS.

Severe hyperkalemia: Absent P-wave, peaked T-wave, wide QRS.

Profound hyperkalemia: Asystole or ventricular fibrillation.



Treatment of hyperkalemia aims to reduce serum potassium level and to counteract the effect of potassium on the heart (see acute renal failure).

Therapy of hyperkalemia

Avoiding all sources of potassium intake

All foods, drugs and I.V. fluids should be free of potassium
 Stored blood transfusion should be avoided (hemolysed cells)

Antagonizing the potassium effect on the heart

Calcium gluconate 10%: 0.5 ml/kg slow I.V. over 10 minutes.

Driving potassium intracellular

Sodium bicarbonate 5%: 4 ml/kg slow I.V. over 10 minutes, or
 Glucose and insulin infusion: 2 ml/kg of glucose 25% + 1 unit insulin/20 ml.

Removing potassium from the body

Peritoneal dialysis

CALCIUM DISORDERS

Calcium is one of the four cations of the body. 99% of the body calcium is present in bones and teeth. The remaining 1% has several important functions mainly neuromuscular irritability, blood coagulation, cardiac action and milk production.

Normal serum calcium is 9-11 mg/dl. It is present in two forms; (1) ionized calcium (60% of total) and (2) non-ionized calcium (40% of total, bound to albumin and globulin). Disorders of calcium include hypocalcemia and hypercalcemia.

Causes of calcium disorders

Hypocalcemia

Acute and chronic renal failure
With hypomagnesemia
With alkalosis
With hyperphosphatemia
Vitamin D deficiency
Malabsorption
Hypoparathyroidism

Hypercalcemia

Vitamin D intoxication
Total parenteral nutrition
Thiazide diuretics
Milk-alkali syndrome
Prolonged immobilization
Malignancy
Hyperparathyroidism

Hypocalcemia

Hypocalcemia can be symptomatic when the reduction of ionized calcium is severe or rapid. Symptoms include weakness, tetany, convulsions and cardiovascular effects (hypotension, cardiac arrhythmias).

Clinical manifestations of tetany

Latent tetany

It needs provocation tests to appear:

- Trousseau sign: Constriction of upper arm results in carpal spasm.
- Peroneat sign: Tapping of tibia over peroneal nerve results in pedal spasm.
- Chvostek sign: Tapping of facial nerve leads to facial contractions.

Manifest tetany

It occurs without provocation test.

- Carpal spasm: Wrist flexion, metacarpophalangeal flexion, interphalangeal extension.
- Pedal spasm: Planter flexion of the ankle joints and toes.
- ± Laryngospasm and convulsions.

Symptomatic hypocalcemia is treated with calcium gluconate 10% solution in a dose of 1 ml/kg, I.V. over 5-10 minutes. The dose can be repeated if tetanic spasms or convulsions are not controlled. Monitoring of the heart during injection is necessary and injection should be discontinued in case of bradycardia. As hypocalcemia is usually associated with total body depletion of calcium, I.V. calcium should be followed by prolonged oral calcium therapy in a dose of 40-80 mg elemental calcium/kg/day. Overdosage is not serious because toxicity following oral administration does not occur.

Hypercalcemia

Hypercalcemia is not an emergency and it usually presents with nonspecific longstanding manifestations as anorexia, vomiting, irritability and weight loss. Treatment includes decreasing calcium intake and decreasing absorption by oral aluminium hydroxide gel and prednisone therapy.

MAGNESIUM DISORDERS

Magnesium is one of the four cations of the body. 70% of total body magnesium is present in bones and teeth. The remaining 30% are distributed in all body tissues, located chiefly intracellular. It is important for neuromuscular irritability and activation of enzymes of carbohydrate metabolism. Normal plasma level is 1.5 - 2.5 mg/dl.

Causes of magnesium disorders

Hypomagnesemia

Diuretic therapy
Malabsorption
Hypoparathyroidism
Prolonged Mg-free I.V. fluids

Hypermagnesemia

Mg-containing antacids
Mg-containing laxatives
Mg-containing enemas
Excessive doses of I.V. Mg.

Symptomatic hypomagnesemia occurs with serum magnesium level below 0.7-1.0 mg/dl. Symptoms include tremors, tetany, convulsions and abnormal cardiac rhythm. Emergency treatment is by Magnesium sulfate 10% solution in a dose of 1.0 ml/kg, slow I.V. in the side tube. This can be followed by oral magnesium therapy.

Symptomatic hypermagnesemia occurs with serum magnesium level above 5 mg/dl. Clinical manifestations include hyporeflexia, respiratory depression and coma. Emergency treatment is by I.V. calcium gluconate, which rapidly reverses these manifestations.

24

Chapter

Acute Renal Failure

Diagnosis

Diagnosis of ARF

Clinical diagnosis

- Early ARE
- Established ARE
- Advanced ARE

Laboratory diagnosis

- Elevated urea and creatinine
- Metabolic acidosis
- Electrolyte disturbance

Cause of ARF

- Prerenal (Functional ARE)
- Renal (Organic ARF)
- Postrenal (Obstructive ARF)

Management

Conservative measures

- Treatment of oliguria or anuria
- Treatment of metabolic acidosis
- Treatment of hyperkalemia
- Treatment of hypocalcemia
- Treatment of hyponatremia
- Treatment of hypertension
- Treatment of convulsions
- Treatment of anemia

Dramatic measures

- Acute peritoneal dialysis
- Acute hemodialysis
- Hemofiltration (CAVH or CWH)

Acute renal failure (ARF) is a complex clinico-laboratory syndrome caused by sudden impairment of renal function and is characterized by:

- 1. Severe oliguria or anuria:** Oliguria is defined as urine output less than 1 ml/kg/hour or less than 300 ml/m²/24 hours. However, it is important to emphasize that acute renal failure may occur without oliguria especially with nephrotoxic drugs (nonoliguric acute renal failure). Severe oliguria or anuria with unrestricted fluid intake results in fluid overload which leads to weight gain, edema, hypertension and may be congestive heart failure and pulmonary edema.
- 2. Acid-base and electrolyte disturbance:** Metabolic acidosis, hyperkalemia, dilutional hypocalcemia and hyponatremia are the main findings. Metabolic acidosis results from decreased renal excretion of acids and hyperkalemia is caused by potassium retention and metabolic acidosis, which causes shift of intracellular potassium to extracellular compartments. These disorders will cause several respiratory, cardiovascular and neurological manifestations. Deep rapid respiration (metabolic acidosis), cardiac arrhythmia (hyperkalemia), convulsions (hypocalcemia and hyponatremia) and coma are the most important manifestations.
- 3. Retention of waste products:** Elevated levels of blood urea and creatinine occur and lead to hyperosmolarity. As each 3 mg/dl rise in blood urea raises serum osmolarity by 1 mOsm/kg H₂O, elevation of blood urea, for instance, from

30 to 120 will raise the serum osmolarity from 285 to 315 mOsm/kg H₂O. At this level, brain edema occurs. However, the associated hypervolemia usually minimizes this effect (see also hyponatremia).

Main pathophysiological changes in ARF

Oliguria or anuria: Fluid overload (edema, hypertension, congestive HF, pulmonary edema).
Acid-base and electrolytes: Respiratory, cardiovascular and neurological manifestations.
Uremia: Hyperosmolarity, uremic encephalopathy, brain edema.

DIAGNOSIS

Diagnosis of acute renal failure should include diagnosis of failure and identification of the causative disease.

Diagnosis of acute renal failure

Diagnosis of acute renal failure depends on a combination of clinical manifestations and laboratory findings.

- 1. Clinical manifestations:** The early manifestations of acute renal failure are usually masked or overshadowed by the clinical features of the causative disease. Therefore, a high index of suspicion is important and the condition should be considered in any disease known to predispose to acute renal failure especially dehydration, hemorrhage, respiratory failure, septicemia, glomerulonephritis and drugs. In established and advanced cases, clinical manifestations are well evident.

Clinical grading of acute renal failure

Grade I: Early acute renal failure

Clinical manifestations of the causative disease are the dominating features.
Oliguria and weight gain may be observed.

Grade II: Established acute renal failure

Severe oliguria or anuria (accurate urine output is important).
Edema and hypertension. Pallor (anemia) may be also evident.
Acidotic breathing: Deep rapid respiration due to metabolic acidosis.

Grade III: Advanced acute renal failure

Congestive heart failure and pulmonary edema (due to volume overload).
Cardiac arrhythmias (due to hyperkalemia).
Convulsions (due to severe hypocalcemia or hyponatremia).
Coma or uremic encephalopathy (due to severe acidosis, marked uremia).
Gastrointestinal bleeding (due to stress ulcers and platelet dysfunction).

- **Inappropriate secretion of antidiuretic hormone (SIADH)** should be differentiated from acute renal failure because in both conditions, oliguria, volume overload and hyponatremia are present. The condition should be suspected in acute lung diseases, mechanical ventilation or acute CNS diseases. In these conditions, excess ADH secretion occurs through stimulation of atrial baroreceptors. Urine osmolarity is above 500 mOsm/liter in prerenal failure and SIADH, and below 340 mOsm/liter in organic renal failure. Urine/plasma osmolarity ratio is above 2 in SIADH, above 1.3 in prerenal failure and below 1.3 in organic renal failure. It is also important to note that ARE and SIADH may coexist in the same patient as in serious trauma or postoperative period.

2. Laboratory diagnosis: With clinical suspicion of acute renal failure, laboratory investigations are essential to confirm the diagnosis. Blood urea and serum creatinine, blood gases (for acid-base balance) and serum electrolyte (Na, K, Ca, Ph) are the most relevant investigations. Other diagnostic procedures as chest X-ray (pulmonary edema or cardiomegaly) and ECG (cardiac arrhythmias) are also important.

Laboratory diagnosis of acute renal failure

Elevated levels of blood urea (above 50 mg/dl) and serum creatinine (above 2 mg/dl).
Metabolic acidosis (low pH, low bicarbonate and may be low PCO₂).
Electrolyte disturbance (hyperkalemia, hyperphosphatemia, hypocalcemia, hyponatremia).

Diagnosis of the cause

Causes of ARF can be classified into three groups according to the mechanism of renal injury, which can be renal hypoperfusion (prerenal causes), organic renal disease (renal causes) or obstruction to urinary flow (postrenal causes). Prerenal causes are the most common, most acute, most reversible in early cases and the main causes of admission to intensive care units. Episodes of ARF may also occur on top of chronic renal failure.

Causes of acute renal failure

**Prerenal causes
(Renal hypoperfusion)**

Hypovolemia
Hypotension (shock)
Hypoxemia

**Renal causes
(Renal disease)**

Acute glomerulonephritis
Acute interstitial nephritis
Acute tubular necrosis

**Postrenal causes
(Urinary obstruction)**

Congenital (stenosis, valves)
Acquired (stones, clots)
Functional (vesicoureteral reflux)

- Hypovolemia occurs with dehydration, hemorrhage, burns.
 - Hypotension occurs with all types of shock and with drugs (antihypertensives).
 - Hypoxemia occurs with all causes of respiratory distress.
 - Acute glomerulonephritis (GN) occurs with acute poststreptococcal GN, rapidly progressive GN, Henoch-Schonlein GN and GN of infective endocarditis.
 - Acute interstitial nephritis occurs with infections (bacterial, viral) or antibiotics (penicillins, cephalosporins, co-trimoxazole,). It is suspected in presence of fever, rash or eosinophilia.
 - Acute tubular necrosis occurs with nephrotoxic drugs (aminoglycosides, potent diuretics) or severe persistent prerenal causes.
 - Other renal causes are hemolytic uremic syndrome and bilateral renal vein thrombosis.
1. **Clinical manifestations:** With prerenal causes, clinical manifestations of the causative disease are well evident and dominating as dehydration, hemorrhage, burns, shock, septicemia or respiratory failure. With renal causes, hematuria (glomerulonephritis), purpura (hemolytic uremic syndrome, renal vein thrombosis) acute hemolytic anemia (hemolytic uremic syndrome, renal vein thrombosis) and flank mass (renal vein thrombosis, cystic disease or tumor) are the most relevant clinical findings. Postrenal causes should be considered in presence of flank masses.
2. **Diagnostic procedures:** Several investigations are usually needed to identify the cause especially in renal and postrenal causes. CBC, CRP, urine analysis and culture, and abdominal ultrasound are the essential initial procedures.

Diagnostic significance of laboratory and imaging abnormalities

Leukocytosis, bandemia, elevated CAP: Septicemia,? lupus nephritis.

Eosinophilia: Interstitial nephritis.

Acute hemolytic anemia: Hemolytic uremic syndrome, renal vein thrombosis, septicemia.

Thrombocytopenia: Hemolytic uremic syndrome, renal vein thrombosis, septicemia.

Low serum complement: Poststreptococcal glomerulonephritis, lupus nephritis.

Gross hematuria: Glomerulonephritis, renal vein thrombosis.

Flank masses by ultrasound: Renal vein thrombosis, tumors, cystic disease, obstructive uropathy.

Finally, it is important to remember that *infections and drugs* can cause acute renal failure through several mechanisms. Infection-associated acute renal failure occurs with septicemia (septic shock or interstitial nephritis), gastroenteritis (dehydration) and urinary tract infection (interstitial nephritis or precipitation of acute episode in obstructive and chronic renal failure). Drug-associated acute renal failure occurs with nephrotoxic drugs (acute tubular necrosis) and several antibiotics (interstitial nephritis).

MANAGEMENT

Management of acute renal failure can be divided into conservative and dramatic measures. Clinical and laboratory monitoring of various parameters are essential. Clinical monitoring should include the level of consciousness, vital signs, state of hydration and urine output. An accurate fluid balance of intake and output is essential. Accurate collection of the urine (with collecting urine bag or urinary catheter) is important and weighing every 12-24 hours is essential as weight gain or weight loss are important parameters in evaluating the efficacy of therapy. Laboratory monitoring should include continuous ECG display (to detect cardiac arrhythmias) and repeated measurements of blood gases, serum electrolytes and blood urea. In shocked patients with questionable intravascular volume, measurement of central venous pressure (CVP) is important to avoid volume overload (shock is hemodynamically classified into hypovolemic, normovolemic and hypervolemic).

Conservative measures

These measures are indicated in early and established ARF and they aim to correct various abnormalities, to provide nutritional support and to prevent infections until natural recovery occurs in 5-10 days. These measures include the following:

1. **Treatment of oliguria or anuria:** It is initially important to differentiate between prerenal causes (characterized by hypovolemia or hypotension) and organic renal diseases (fluid overload with edema, hypertension, liver enlargement, basal crepitations, gallop rhythm). Dehydration, bleeding or burns clearly indicate hypovolemia. Treatment of oliguria is made in the following steps:
 - a. **Volume expansion:** It is indicated in all cases except those with frank fluid overload and hypervolemia. Ringer's lactate or normal saline is given I.V. in an amount of 20 ml/kg over 20-30 minutes. Following this infusion, the hypovolemic patient will usually void within 2 hours. Failure of urination after 2 hours is an indication of diuretic therapy.

- b. Diuretic therapy:** Induction of diuresis with diuretics is indicated in those with fluid overload and those who failed to respond to the challenge test of volume expansion. It aims to convert oliguric renal failure into nonoliguric renal failure, which is easier to manage especially for fluid overload and hyperkalemia. Furosemide is initially given I.V. in a dose of 2 mg/kg. If no response within one hour, a second dose of 10 mg/kg, I.V. may be given. Furosemide corrects oliguria through its diuretic effect and renal cortical vasodilating effect (through direct or prostaglandin-mediated effects). Mannitol 20% can also be given in a dose of 5 ml/kg, I.V. over 30 minutes. It is mainly useful when it is given in the early stages and it has the same effects of furosemide (diuretic and cortical vasodilating effect).
 - c. Dopamine infusion:** A low dose dopamine (2-5 mcg/kg/minute) may be also used in absence of hypertension. It has a renal cortical vasodilating effect (increases cortical blood flow) and probably a diuretic effect (natriuretic effect). These two actions are independent of its inotropic effect on the heart, which is mainly evident with doses above 5 mcg/kg/minute. It is important to remember that infants are more resistant to alpha and beta effects of dopamine; therefore, they may show improved urine output with doses as high as 15-20 mcg/kg/minute.
 - d. Fluid restriction:** It is indicated in patients who failed to obtain an adequate urine flow following volume expansion, diuretics and dopamine infusion. The total daily fluid intake (oral and parenteral) should equal the insensible water losses (300 ml/m^2) plus the measured urine output and any other losses (GIT, draining tubes etc.). Care should be taken to avoid hypovolemia and hypotension. In case of volume overload, a negative balance is required where the total daily intake should be less than the calculated amount. The used intravenous solution should be made of glucose 5 or 10% and isotonic saline in a ratio of 4:1. Potassium should not be added to the solution until an adequate urine flow is obtained.
- 2. Treatment of acid-base and electrolyte disturbances:** Metabolic acidosis, hyperkalemia, hyperphosphatemia, hypocalcemia and hyponatremia are the most commonly encountered problems.
- a. Treatment of metabolic acidosis:** A moderate degree of metabolic acidosis is usually present. Severe acidosis with pH below 7.15 and bicarbonate below 10 mEq/liter requires an urgent therapy to raise pH above 7.2 and bicarbonate above 12 mEq/liter. Sodium bicarbonate 5% is given in a dose of 4 ml/kg, I.V. over 10 minutes. Blood gas analysis is repeated after 30 minutes and the dose can be repeated if necessary. Other causative factors as hypoxemia and shock should be urgently corrected.
 - b. Treatment of hyperkalemia:** Serum potassium level above 6 mEq/litre is serious and can lead to cardiac arrhythmia which can be mild (prolonged P-R interval, peaked T-wave), moderate (peaked T-wave, wide QRS), severe (absent P-wave, peaked T-wave, wide QRS), or profound (asystole or ventricular fibrillation). Treatment of hyperkalemia includes the following:

- (i) *Avoiding all sources of potassium intake:* All foods, drugs and I.V. fluids should be free of potassium. Stored blood transfusion should be avoided because it contains hemolysed cells and high potassium content.
 - (ii) *Antagonizing the potassium effect on the heart:* Calcium gluconate 10% is given in a dose of 0.5 ml/kg, I.V. over 10 minutes. Monitoring of heart during infusion is essential and injection should be discontinued if bradycardia occurs. Duration of action is only one hour.
 - (iii) *Driving potassium intracellular:* Sodium bicarbonate 5% solution is given in a dose of 4 ml/kg, I.V. over 10 minutes. Bicarbonate lowers the potassium level through correction of acidosis and shift of extracellular potassium to intracellular compartment. Glucose and insulin infusion has the same effect. Glucose 50% (1 ml/kg) and regular insulin (1 unit/10 ml glucose 50%) are given I.V. over 1 hour. Glucose 25% (2 ml/kg) and regular insulin (1 unit/20 ml glucose 25%) is an alternative when glucose 50% is not available.
 - (iv) *Removing potassium from the body:* Peritoneal dialysis is indicated in case of persistent hyperkalemia above 7 mEq/litre in spite of all above measures or in presence of moderate to severe ECG changes.
- c. ***Treatment of hyperphosphatemia and hypocalcemia:*** High phosphorus level above 7 mg/dl necessitates therapy with aluminium hydroxide gel (Epicogel or mucogel suspension). It is given orally or through a nasogastric tube in a dose of 2 ml/kg/day, divided into 3-4 doses. It lowers the serum phosphorus level through increasing the fecal phosphate excretion. Lowering of serum phosphorus level usually corrects the hypocalcemia. Calcium gluconate 10% solution (1 ml/kg, slow I.V.) is only indicated in symptomatic hypocalcemia with tetany or convulsions.
- d. ***Treatment of hyponatremia:*** Fluid restriction is usually sufficient to correct the dilutional hyponatremia. With serum sodium level below 120 mEq/liter, brain edema may occur and therapy with hypertonic saline 3% solution is indicated. It is given I.V. in a dose of 5-10 ml/kg with a rate of 1 ml/minute. The dose can be repeated after 2-4 hours if serum sodium level is still below 120 mEq/liter. Each 1 ml/kg of this solution will raise the serum sodium level by about 1 mEq/litre (for accurate correction, see hyponatremia).
3. ***Treatment of hypertension:*** In acute renal failure, hypertension occurs mainly due to volume overload and occasionally (as in hemolytic-uremic syndrome) due to high plasma renin level. Hypertension can lead to hypertensive heart failure and pulmonary edema. Hypertensive encephalopathy occurs with blood pressure above the level of cerebral autoregulation (above 160 mmHg). Moderate hypertension can be treated with sublingual nifedipine (0.2-0.5 mg/kg/dose) or I.V. or I.M. hydralazine (0.2-0.5 mg/kg/dose). In extremely severe cases, I.V. diazoxide (2-5 mg/kg) or sodium nitroprusside infusion (0.5-0.5 mcg/kg/minute) can be used. After initial control, therapy can be continued with oral captopril (0.5-2.0 mg/kg/day).

4. **Treatment of convulsions:** Diazepam, given I.V. in a dose of 0.3-0.5 mg/kg is the drug of choice for immediate control. Correction of the precipitating factors as hypocalcemia, hyponatremia or hypertension is equally important.
5. **Treatment of anemia:** Mild anemia is commonly present in acute renal failure. Small packed red cell transfusion (5 ml/kg) is only indicated when hemoglobin level falls below 7 gm/dl.
6. **Control of infections:** Unrecognized or uncontrolled infections account for one third of deaths in acute renal failure. Infections should be expected and properly diagnosed by appropriate cultures including blood and urine cultures. Two precautions regarding the choice of antibiotics and drug dosage are important: (1) nephrotoxic drugs as aminoglycosides are better to be avoided. Chloramphenicol and cefoperazone (Cefobid) have the advantage of being mainly excreted through the liver, (2) with marked renal insufficiency, dosage adjustment should be made by reduction of dosage or frequency of administration.
7. **Nutritional support:** Nasogastric tube feeding or oral feeding should replace the I.V. fluids as soon as the clinical condition permits. If I.V. fluid therapy should be used for more than 4 days, amino acid infusion should be added in a dose of 10 ml/kg/day, given over 4-6 hours. Diet is limited initially to carbohydrates and fats. Proteins can be allowed in small amounts during the recovery phase.

Dramatic measures

These measures are indicated in advanced ARF with severe water, acid-base or electrolyte abnormalities.

1. **Acute peritoneal dialysis:** This simple dramatic measure is frequently life-saving in infants and young children especially when initiated early. It is more efficient in children, compared to adults, due to the relatively larger peritoneal surface area. The indications of peritoneal dialysis in acute renal failure are either clinical or laboratory.

Indications of acute peritoneal dialysis in ARF

Clinical indications

- Anuria not responding to volume expansion, diuretics and dopamine infusion.
- Volume overload with congestive heart failure or pulmonary edema.
- Deteriorating neurological state in spite of the conservative measures.
- Gastrointestinal bleeding due to uremic platelet dysfunction.

Laboratory indications

- Blood urea above 150 mg/dl or rapidly rising level.
- Severe persistent metabolic acidosis (pH below 7.1) inspite of the conservative measures.
- Severe persistent hyperkalemia (above 7.0 mEq/litre)
- Hypernatremia (above 160 mEq/litre) with volume overload.
- Hyponatremia (below 120 mEq/litre) with volume overload.
- Symptomatic hypocalcemia (tetany or convulsions) with hyperphosphatemia.

Peritoneal dialysis depends on the idea that the peritoneum is a semipermeable membrane across which water and solute diffuse along their concentration gradients. Peritoneal dialysis is made by repeated cycles or runs of infusion and draining out of the dialysate solution. Initial cycles are made with 20 ml/kg/cycle and the amount is then increased gradually to a final range of 40-50 ml/kg/cycle. The dialysate solution should be warmed to 38°C before infusion, and the dialysis catheter can be left in place for up to 72 hours. Peritoneal dialysis should be only made with personnel experienced with the technique and oriented with the suitable dialysate solutions and the possible complications (see therapeutic interventions).

2. **Acute hemodialysis:** It is a more efficient measure than peritoneal dialysis but it is also more difficult, more expensive and necessitates sophisticated expensive hemodialyzers, disposable filters and tubing. It is mainly indicated in situations where peritoneal dialysis is contraindicated as with infected abdominal wall, recent abdominal surgery, peritoneal adhesions or diaphragmatic defect. It depends on the same idea of peritoneal dialysis where water and solute diffuse across a semipermeable membrane from blood to dialysate or vice versa along their concentration gradients. Acute hemodialysis can be made with either 2 catheters (venous and arterial) or one double-lumen catheter placed in a vein. Infants and children can safely tolerate a blood flow rate in the range of 2-5 ml/kg/minute. Mannitol 20% may be needed in a dose of 5-10 ml/kg, I.V. over 30 minutes in patients with blood urea above 150 mg/dl.
3. **Hemofiltration:** It is a form of continuous renal replacement therapy, which does not adversely affect the cardiopulmonary function as in peritoneal dialysis and hemodialysis. It can be used in the same indications but it is particularly useful in those with compromised cardiopulmonary function or with severe coagulopathies. It is a simple safe procedure with almost no contraindications. It can be made by one of two methods; continuous arteriovenous hemofiltration (CAVH) or continuous venovenous hemofiltration (CVVH). It depends on the idea that water and solutes are extracted from the blood by the development of a hydrostatic pressure gradient and subsequent filtration.

Treatment of the cause

Conservative and/or dramatic measures should be combined with the appropriate treatment of the causative disease. In prerenal causes, hypoxemia and shock should be urgently corrected with the nonspecific respiratory or cardiovascular support in addition to the specific treatment of the causative disease. In postrenal causes, urological consultation for relief of obstruction should be considered after the initial stabilization.

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Chapter

Acute Hepatic Failure

Diagnosis

Diagnosis of AHF

Clinical diagnosis

- Progressive jaundice
- Gastrointestinal bleeding
- Hepatic encephalopathy

Laboratory diagnosis

- Rising bilirubin level
- Low serum albumin
- Prolonged prothrombin time
- Acid-base and electrolyte disorders

Cause of AHF

- Viral hepatitis
- Toxic or drug-induced hepatitis
- Metabolic hepatitis

Management

Conservative measures

- Nutritional support
- Reduction of blood ammonia
- Control of bleeding
- Control of infection
- Treatment of cerebral edema
- Treatment of respiratory failure
- Treatment of renal failure
- Treatment of ascites

Dramatic measures

- Charcoal hemoperfusion
- Peritoneal dialysis
- Artificial hepatic support system
- Liver transplantation.

Acute hepatic failure (or fulminant hepatic failure) is a catastrophic event with mortality rate approximating 70%. It is characterized by sudden impairment of hepatic function with disturbed metabolic, excretory and detoxifying functions. The high mortality rate is related to the several serious effects (gastrointestinal hemorrhage, brain failure, respiratory failure, renal failure) and the necessity for prolonged supportive care over weeks until natural recovery occurs.

Pathophysiological changes of acute hepatic failure

Disturbed metabolic functions

- Hypoalbuminemia due to decreased hepatic synthesis: Fluid overload.
- Hypoglycemia due to disturbed carbohydrate metabolism.
- Coagulation defect due to decreased synthesis of coagulation factors.
- Retention of some amino acids: Hepatic encephalopathy.
- Retention of some fatty acids: Hepatic encephalopathy.
- Metabolic acidosis and respiratory alkalosis.
- Electrolyte disturbances: Hyponatremia and hypokalemia.

Disturbed excretory function

- High serum bilirubin level except in Reye syndrome.
- High serum bile salts: Serious effect on the kidney (renal failure).

Disturbed detoxifying function

- High blood ammonia level: Hepatic encephalopathy.

DIAGNOSIS

Diagnosis of acute hepatic failure

1. **Clinical manifestations:** Early manifestations include persistent vomiting, bruising and altered behavior. In established cases, jaundice and gastrointestinal bleeding are well evident. In advanced cases, several system failures occur.

Clinical grading of acute hepatic failure

Grade I: Early acute hepatic failure

Protracted vomiting and bruising.

Altered behavior: Euphoria or drowsiness, disturbed sleep rhythm.

Grade II: Established acute hepatic failure

Progressive jaundice (except in Reye syndrome).

Gastrointestinal bleeding (in 70% of cases): Due to stress ulcers, coagulopathy and DIC.

Hepatic encephalopathy: Confusion, stupor, light coma or deep coma.

Grade III: Advanced acute hepatic failure

Infections: Septicemia, aspiration pneumonia, peritonitis, urinary tract infection.

Cerebral edema: Hyperventilation, hyper-reflexia, rigidity.

Respiratory failure: Due to fluid overload and neurogenic pulmonary edema.

Renal failure (hepatorenal syndrome): Due to bile salts, prostaglandins, endotoxins.

- **Hepatic encephalopathy** occurs due to high blood ammonia level (due to increased production by intestine and kidneys and decreased metabolism of ammonia to urea by damaged hepatic cells). Increased blood level of some amino acids (methionine, glutamine, tryptophan) and short chain fatty acids (butyric acid) are also responsible.
- **Cerebral edema** occurs due to the toxic effect of ammonia and other metabolites on brain cells and the pathologic cerebral vasodilatation. It is the cause of death in about 50% of cases.

2. **Laboratory findings:** Although a 10 to 100-fold rise of transferases (aspartase and alanine aminotransferase) occur in acute hepatic failure, the degree of elevation does not correlate to the severity of failure. A better correlation can be made by monitoring serum bilirubin, albumin and prothrombin time. Other associated laboratory findings as acid-base and electrolyte disturbances should not be overlooked.

Laboratory findings of acute hepatic failure

Findings related to hepatic injury

High serum transferases (AST and ALT): Poor correlation to severity of AHF.

Rising bilirubin level (above 10 mg/dl).

Low serum albumin (below 3 gm/dl)

Prolonged prothrombin time.

High blood ammonia level (above 150 mcg/dl).

Other findings

Metabolic acidosis and respiratory alkalosis.

Hypokalemia, hyponatremia, hypoglycemia.

± DIC, acute renal failure (elevated blood urea, creatinine).

Diagnosis of the cause

Viral hepatitis, toxic or drug induced hepatitis and metabolic hepatitis are the main three categories of acute hepatic failure. History may reveal exposure to drugs and examination may reveal shock, hypoxia or septicemia. Differentiation between different types of viral hepatitis can only be made by laboratory investigations. However, hepatitis B and hepatitis D are the most common types associated with fulminant hepatitis and acute hepatic failure.

Causes of acute hepatic failure

Infective hepatitis

Viral hepatitis: Hepatitis viruses, cytomegalovirus, Epstein-barr virus.

Bacterial hepatitis: Fulminant sepsis.

Toxic or drug-induced hepatitis

Commonly used drugs: Paracetamol, erythromycin, isoniazid, salicylates.

Other drugs: Chlorpromazine, antiepileptics, antineoplastics, androgens.

Metabolic hepatitis

Advanced shock with multiple organ system failure.

Reye syndrome (acute encephalopathy with fatty infiltration of the liver).

MANAGEMENT

Management of acute hepatic failure can be divided into conservative and dramatic measures. **Clinical and laboratory monitoring** of various parameters are essential. Clinical monitoring should include neurological manifestations (level of consciousness, convulsions, rigidity, vital signs (HR, RR, B.P. and temperature), evidence of bleeding (site, amount), urinary output, evidence of fluid retention (edema, ascites) and evidence of infection. **Laboratory evaluation** should include repeated measurements of liver functions (transaminases, bilirubin, serum albumin, prothrombin time), renal function (blood urea, creatinine), serum electrolytes (Na, K, Ca, Mg), blood gases and blood ammonia level (normal value is 40-80 mcg/dl).

Conservative measures

Unfortunately, there is no specific therapy that can promote hepatic regeneration and the treatment is mainly supportive and it aims to preserve life, to prevent and to deal with complications until natural recovery takes place. Conservative treatment includes the following:

1. **Water, electrolyte and nutritional support:** It aims to keep the child normovolemic with normal electrolytes and blood sugar level. **I.V. fluid therapy** is initially indicated in patients with altered consciousness or in those with gastrointestinal bleeding. A solution of glucose 10% and normal saline in a ratio of 4:1 is initially used in an amount equal to daily requirement. However, the calculated amount should be reduced by 30% in patients with fluid retention or cerebral edema (2-3 ml/kg/hour).

Potassium chloride solution 15% is added to the I.V. fluid in an amount of 1.75 ml for each 100 ml of the glucose saline mixture to make a potassium concentration of 35 mEq/litre. Subsequent change of Na or K contents will depend on serum levels. *Daily calcium and magnesium supplementation* is important if I.V. fluid therapy is continuing for several days. Water soluble vitamins may be added to the I.V. fluids (parenterovite) **Salt free albumin 20%** (5 ml/kg, I.V.) is indicated in severe hypoalbuminemia and fluid overload. *Nasogastric feeding or oral feeding* can be gradually resumed in recovering patients and after control of gastrointestinal hemorrhage. *Total parenteral nutrition* should be started if oral nutrition cannot be maintained.

2. **Reduction of blood ammonia:** As high blood ammonia level is responsible for hepatic encephalopathy, reduction of blood ammonia level is important. Proteins are completely eliminated from the diet. Neomycin is given through a nasogastric tube in a dose of 50-100 mg/kg/day in 4 divided doses (every 6 hours) to sterilize the bowel. Lactulose is also used to decrease microbial ammonia production. It is given orally or through a nasogastric tube in a dose of 10 ml/6 hours. The dose should be adjusted to produce several loose motions per day.
3. **Control of bleeding:** The blood in the stomach should be aspirated through a nasogastric tube and an antacid (aluminium hydroxyl gel) is given in a dose of 10 ml, 3-4 times/day. Cimetidine (H_2 receptor antihistaminic) may also be used in a dose of 40 mg/kg/day in 3-4 divided doses to reduce gastric acidity. Lactulose enema (one volume lactulose and 3 volumes water) may be used to clean the bowel. Coagulation defect is transiently corrected by vitamin K1 (5-10 mg/kg/day, I.V.) and Fresh frozen plasma (10 ml/kg, I.V.). Whole blood transfusion (20 ml/kg) is indicated in severe hemorrhage to compensate for blood loss.
4. **Control of infections:** Several infections may occur and are commonly the cause of death. Infections should be considered in the following situations: (1) New onset of fever or leukocytosis, (2) Sudden development of hepatorenal failure, (3) Severe respiratory distress, (4) Deterioration of the level of consciousness, (5) Abdominal rigidity (peritonitis). Septicemia, pneumonia, peritonitis and urinary tract infection should be vigorously treated with the appropriate antibiotics and according to the results of cultures.
5. **Treatment of cerebral edema:** In patients with manifestations of increased intracranial pressure (hyperventilation, rigidity, sluggish pupillary reactions), rapid measures to reduce the intracranial pressure should be used. These measures include head elevation 30° in neutral position, mechanical hyperventilation (to keep PCO_2 between 25-30 mm Hg) and mannitol therapy (see increased intracranial pressure). It is the cause of death in 50% of cases.
6. **Treatment of respiratory failure:** It occurs in 50% of cases due to neurogenic pulmonary edema, volume overload, intrapulmonary shunting or aspiration pneumonia. Oxygen therapy may be sufficient in some cases, but positive pressure support (CPAP or IMV) is necessary in severe cases. However, high pressure has the risk of impairment of hepatic circulation and increased hepatic ischemia.

7. **Hepatorenal syndrome:** It occurs in up to 70% of cases due to increased bile salts, adverse effects of prostaglandins and endotoxemia. Iatrogenic hepatorenal syndrome may occur due to aggressive diuresis, aminoglycosides or nonsteroidal anti-inflammatory drugs. Diagnosis is made by the presence of oliguria and elevated blood urea level. Central venous pressure monitoring is essential and CVP should be kept between 3-8 mm Hg. In absence of pulmonary edema, mannitol and furosemide therapy may be useful to induce diuresis.
8. **Treatment of fluid retention and ascites:** Fluid restriction is the initial step. Diuretics are preferably to be avoided, but if necessary, spironolactone (5 mg/kg/day, in 2 divided doses) is preferable as it preserves potassium. Abdominal paracentesis is indicated when ascites is causing mechanical compression and dyspnea.

Dramatic measures

These measures are indicated in advanced cases to provide a more efficient supportive care until natural recovery occurs. **Charcoal hemoperfusion** is an effective procedure, which can reverse coma and cause temporary arousal. It is mainly useful when it is performed early and repeated frequently. **Artificial hepatic support** depends on removal of toxic substances and addition of activated factors, which aim to provide better circumstances for liver cells to regenerate. **Liver transplantation** is the ideal dramatic measure in severe deteriorating cases.

Comparison between ARF and AHF

	Acute Renal Failure	Acute Hepatic Failure
Metabolic effects		
Water	Fluid overload (±)	Fluid overload (±)
Acid-base	Metabolic acidosis	M. acidosis and R. alkalosis
Electrolytes	Hyperkalemia	Hypokalemia
Systemic effects		
CNS	Uremic encephalopathy	Hepatic encephalopathy
Respiratory	Pulmonary edema (±)	Pulmonary edema (±)
CVS	Hypertension, arrhythmia	Hypertension (±)
GIT bleeding	Mild bleeding (±)	Serious bleeding
Recovery period	Short (5-10 days)	Long (weeks)
Mortality rate	Low	High (70%)

- **Fluid overload** in ARF is due to oliguria and fluid retention, while in AHF it is due to hypoalbuminemia, anti-diuretic hormone like activity and associated renal failure.
- **Encephalopathy** in ARF is due to uremia, severe acidosis and severe hyponatremia while in AHF it is due to high blood ammonia level, some amino acid retention and cerebral edema.
- **Mortality rate** is high in AHF because supportive therapy is more difficult and recovery period is long.

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Chapter

Diabetic Ketoacidosis

Diagnosis

Clinical manifestations

- I. Vomiting, polyuria
- II. Dehydration, acidosis
- III. Shock, coma

Laboratory diagnosis

Hyperglycemia
Ketonemia
Metabolic acidosis
Glucosuria, ketonuria

Management

During ketoacidotic phase

I.V. fluid therapy
Insulin therapy
Control of infections
Treatment of complications

During post-acidotic phase

Diet
Insulin therapy
Close observation

Diabetes mellitus is the commonest endocrine-metabolic disease with an incidence of 0.2% (2/1000). Approximately 30% of newly diabetic children will present with diabetic ketoacidosis and 10% of patients with diabetic ketoacidosis are admitted in a comatose state. Diabetic ketoacidosis is a medical emergency, which carries a mortality rate of about 10%.

PATHOPHYSIOLOGY

The basic defect in type I diabetes is the autoimmune destruction of pancreatic islets leading to beta cell failure and decreased or absent insulin secretion. In diabetic ketoacidosis, the episode can be precipitated by several factors and it is characterized by various metabolic and systemic derangements.

Causes and pathophysiological changes of diabetic ketoacidosis

Causes or precipitating factors

Infections.
Insulin underdosage in a diabetic child.
Other factors as trauma or psychological disturbance.

Pathophysiological changes

Hyperglycemia: Leads to hyperosmolarity, glucosuria, osmotic diuresis (polyuria), polydipsia.
Proteolysis: Leads to polyphagia, abdominal pain, vomiting, weight loss.
Lipolysis: Leads to ketonemia (ketoacidosis) and ketonuria.
Dehydration: Results from vomiting and polyuria and leads to hypovolemic shock.
Coma: Results from dehydration, acidosis and hyperosmolarity.

Plasma osmolarity = $2(\text{Na} + \text{K}) + (\text{glucose}/18) + (\text{urea}/3)$. Normal plasma osmolarity is 285–295 mOsm/kg H_2O . From the above formula, each 100 mg/dl rise in blood glucose level will result in 5–6 mOsm/kg H_2O rise in plasma osmolarity. At level of 310 mOsm/kg H_2O , brain edema occurs (see also hyponatremia and acute renal failure).

DIAGNOSIS

Diagnosis of diabetic ketoacidosis depends on a combination of suggestive clinical manifestations and confirmatory laboratory findings. Clinical manifestations vary according to the severity of the condition (see below). Diabetic ketoacidosis should be the first possibility in a child presenting with vomiting, dehydration and acidosis. In an infant, these manifestations are mostly due to severe gastroenteritis.

Diagnostic criteria of diabetic ketoacidosis

Clinical manifestations

Early manifestations: Vomiting, polyuria, \pm abdominal pain, \pm fever.

Next manifestations: Dehydration and acidotic breathing (deep rapid respiration).

Late manifestations: Shock and coma.

Complications: Brain edema, pulmonary edema, cardiac arrhythmias.

Laboratory diagnosis

Hyperglycemia (blood sugar level above 300 mg/dl).

Ketonemia (positive ketone reaction at 1:2 dilution or greater).

Metabolic acidosis (pH below 7.3 and bicarbonate below 15 mEq/liter).

Glucosuria and ketonuria.

- **Brain edema** is commonly iatrogenic due to rapid correction of hypovolemia and hyperglycemia. The reduced plasma osmolarity will cause fluid shift from blood to brain cells. Brain edema also occurs with the uncommon type of hyperglycemic hyperosmolar nonketotic coma (see below).
- **Pulmonary edema** may occur due to hyperosmolarity or myocardial failure and usually necessitates endotracheal intubation and positive pressure support.
- **Cardiac arrhythmias** may occur due to hyperkalemia (secondary to acidosis), hypokalemia (during therapy) or hypocalcemia.

Diabetic ketoacidosis should not be confused with several medical and surgical conditions, which present clinically with similar clinical manifestations. Septicemia, urinary tract infection and acute suprarrenal failure should be considered. In addition, in a diabetic child presenting with coma, diabetic ketoacidosis should be differentiated from other causes of coma.

Differential diagnosis of diabetic ketoacidosis

From other medical and surgical conditions

Septicemia (fever and vomiting) or urinary tract infection (fever, vomiting, abdominal pain).

Acute suprarrenal failure (vomiting, abdominal pain, dehydration, shock).

Reye syndrome (severe vomiting and disturbed consciousness).

Surgical emergency as appendicitis or intestinal obstruction (vomiting, abdominal pain).

From other causes of coma in a diabetic child

Hyperglycemic hyperosmolar nonketotic coma (HHNC).

Hypoglycemic coma.

Coma due to accidental causes (head trauma, CNS infection, etc.).

Hyperglycemic hyperosmolar nonketotic coma (HHNC): It is uncommon but serious type of coma with a high mortality rate. It is characterized by marked hyperglycemia (blood glucose above 600 mg/dl), hyperosmolarity (above 350 mOsm/kg H₂O) but without ketosis or acidosis (a degree of nonketotic acidosis may be present). Clinically, severe dehydration, coma and other neurological manifestations (convulsions, hemiparesis) are usually present. The degree of coma is directly related to the degree of hyperosmolarity. It is important to emphasize that this type of coma is not peculiar to diabetes and it can occur in several other conditions.

Causes of hyperglycemic hyperosmolar nonketotic coma (HHNC)

Disease states

Head trauma (due to increased endogenous catecholamines and corticosteroids).
Severe infection and dehydration.
Diabetes mellitus.

Iatrogenic causes

Drugs: Catecholamines, corticosteroids, diazoxide, phenytoin.
Total parenteral nutrition.
Suprasellar surgery.

Hypoglycemic coma: It is a major complication of insulin therapy. It is usually precipitated by insulin overdosage or increased exercise without corresponding reduction in insulin dosage. Fasting or reduction in diet without corresponding reduction in insulin dosage is also an important cause. Clinically, sweating and convulsions may occur. Blood sugar level is usually below 50 mg/dl. It responds dramatically to intravenous glucose in an amount of 2-4 ml/kg.

Causes of hypoglycemia

Hormonal causes

Hormonal excess: Hyperinsulinism due to beta cell tumor or hyperplasia.
Hormonal deficiency: Growth hormone, thyroxine or adrenocortical deficiency.

Metabolic causes

Carbohydrates: Glycogenosis type I, galactosemia, acute hepatic failure.
Aminoacids: Maple syrup urine disease, propionic acidemia.

Caloric disorders

Inadequate intake: Starvation, malabsorption, protein calorie malnutrition.
Excessive utilization: Severe exercise, fever, cold, renal glucosuria.

Drug-induced hypoglycemia

Insulin overdosage or overdosage of oral antidiabetic agents.
Salicylate poisoning, propranolol overdosage.

Ketotic hypoglycemia

It is the most common cause. Age of onset is between 1 - 5 years.
Hypoglycemia occurs in attacks and is associated with ketonuria.

MANAGEMENT

Management of diabetic ketoacidosis can be divided into 3 phases (ketoacidotic, post-acidosis and lifelong phases). The 3 phases differ in duration, place of management, insulin dosage and diet.

Phases of management of diabetic ketoacidosis

Ketoacidotic phase

Usually takes 36-48 hours. Preferably managed in ICU.

Aims to correct shock, dehydration, acidosis and hyperglycemia.

Insulin used is the regular insulin given by I.V. Infusion.

Post-acidotic phase

Usually takes 2-3 days. Can be managed in ordinary wards.

Aims to initiate oral feeding and to adjust insulin dosage.

Insulin used is the regular insulin given subcutaneous every 6-8 hours.

Lifelong phase

Initial few days in the hospital, then lifelong home management.

Aims to control blood sugar level and to normalize the life of the child.

Insulin used is a combination of intermediate and regular insulin in a ratio of 2:1 given as a single or twice daily subcutaneous injections.

Management during the ketoacidotic phase

Patients with diabetic ketoacidosis are preferably managed in ICU especially in presence of severe shock, coma or respiratory failure. Management needs a constant attention and teamwork among physician, nurse and laboratory.

Monitoring of various clinical and laboratory findings and recording in a flow-sheet is essential. *Clinical monitoring* should include the level of consciousness, vital signs, state of hydration and urine output. Continuous display of ECG is important to detect cardiac arrhythmias. *Laboratory monitoring* should be made initially every 2-4 hours and should include blood sugar level, blood gases (to detect metabolic acidosis), serum electrolytes (Na, K, Ca) and urine analysis for sugar and acetone. Initial blood sugar sample should be sent to the laboratory, then bedside analysis can be simply made by using the commercial strips (Hemoglukorest) and capillary blood samples. However, accuracy of this test should be checked every 6-8 hours by the standard laboratory method. When an infection seems to be the precipitating factor, blood and urine cultures should be made.

When the patient is in coma, **oxygen therapy** is important and a nasogastric tube is inserted to evacuate the stomach to avoid vomiting and aspiration. The main lines of management are:

1. **I.V. fluid therapy:** It is the most important line of therapy and it aims to correct shock, acidosis and dehydration. Treatment can be divided into three stages:
 - a. **Shock therapy:** 20 ml/kg of normal saline or Ringer's lactate is given over 1 hour. In severe cases, the amount can be given over 10-15 minutes and can be even repeated.

- b. Deficit therapy:** The amount needed is usually 80-100 ml/kg and it is given over 10 hours. Treatment is started with normal saline until blood sugar level becomes below 300 mg/dl, then the solution is changed to glucose 5% and saline mixture in a ratio of 1:1. Four precautions are important; (1) half the calculated amount is given over the first 4 hours and the other half over the next 6 hours, (2) one or two hours after initiation of insulin therapy, potassium chloride solution (15%) is added to the deficit solution in an amount of 1.5 ml for each 100 ml of the solution. This amount will make a potassium concentration of 30 mEq/litre, (3) correction of metabolic acidosis with sodium bicarbonate is only indicated in severe acidosis (with pH below 7.15 and bicarbonate below 10 mEq/litre). A single dose of sodium bicarbonate 5% (2 ml/kg, I.V. over 10 minutes) is usually sufficient as complete correction will occur with I.V. fluid therapy and insulin therapy, (4) re-evaluation of deficit therapy should be made after 6 hours in the light of clinical and laboratory status.
- c. Maintenance therapy:** It is given over the next 24 hours. The solution used is a mixture of glucose 5% and saline in a ratio of 4:1 with addition of 1 ml of potassium chloride solution (15%) to each 100 ml of the mixture. Alternatively, Kadalex and saline mixture in a ratio of 4:1 can be used. The amount given equals the daily requirements plus 10-20% extra-amount if polyuria is continuing.

Calculation of maintenance daily requirements

100 ml/kg/day... for the first 10 kg body weight.

50 ml/kg/day... added for each kg from 11 - 20 kg.

20 ml/kg/day... added for each kg above 20 kg.

- A child 25kg needs $(10 \times 100) + (10 \times 50) + (5 \times 20) = 1600$ ml/day.

- 2. Correction of hyperglycemia by insulin therapy:** Once I.V. fluids are started and shock therapy is going on, insulin therapy is initiated. Insulin is given by the *low-dose continuous I.V. infusion method*. With this method, insulin is given through a separate I.V. line. 50 units of regular insulin are added to 500 ml saline (in this solution, each 1 ml contains 0.1 unit of insulin). Therapy is started by continuous infusion in a dose of 0.1 unit/kg/hour (i.e. 1 ml/kg/hour) without a bolus dose. For instance, if the patient's weight is 25 kg, give the infusion at a rate of 25 ml/hour, i.e. 8 drops/minute. When blood glucose level reaches below 300 mg/dl, the dose of insulin can be reduced to 0.05 unit/kg/hour for several hours then the infusion is discontinued and regular insulin is given in a dose of 0.2 - 0.4 unit/kg, every 6 - 8 hours, subcutaneous.
- 3. Control of infections:** When an infection seems to be the precipitating factor, a broad-spectrum antibiotic as cefuroxime is given I.V. in a dose of 50-100 mg/kg/day, divided into 2-3 doses. Therapy can be adjusted according to the results of cultures.

I.V. fluid therapy and insulin therapy in a 3 years old girl with DKA



Two separate I.V. lines and 2 infusion pumps are used.

4. **Treatment of complications:** *Brain edema* is a serious complication and it is the main cause of death in fatal cases. It usually occurs during therapy when blood sugar level starts to decline. Clinical manifestations include deterioration of the level of consciousness, hyperreflexia, hyperventilation and/or sluggish pupillary reaction to light. Urgent measures to lower the elevated intracranial pressure are indicated. These measures include head elevation 30° in neutral position, mechanical hyperventilation to keep PaCO₂ between 25-30 mm Hg and mannitol therapy. Also, the rate of infusion of fluid therapy should be reduced (see increased intracranial pressure). *Pulmonary edema* may also occur due to hyperosmolarity and/or myocardial failure and it necessitates endotracheal intubation and positive pressure support. *Cardiac arrhythmias* may occur due to electrolyte disturbance (hyperkalemia, hypokalemia or hypocalcemia) and these abnormalities should be urgently corrected (see electrolyte disorders).

At the end of this stage, which usually takes 36-48 hours, the patient should be conscious, full hydrated, with blood sugar below 200 mg/dl and ready for oral intake.

Management during the post-acidotic phase

1. **Diet:** As soon as the patient is ready to take fluids by mouth, sips of water may be given for few hours until it is evident that vomiting and gastric dilatation are unlikely to occur. Then, soft and liquid diet is given at 3 hours intervals, consisting mainly of carbohydrates as fruit juice, gelatin desserts, skimmed milk and fat free ice-cream. Within 1-2 days on this regimen, the child should be ready for average diet.
2. **Insulin therapy:** Regular insulin is given subcutaneous in a dose of 0.2-0.4 unit/kg, every 6-8 hours, before meals. Blood glucose level should be monitored before and 2 hours after each meal and insulin dosage can be adjusted to keep blood

sugar level between 100 - 180 mg/dl. This regimen is continued for 24 hours after the child is already eating average diet. The total daily dose is then calculated to be used as guide for dosage in the next phase of management. It is important to remember that in case of children presenting with classic symptoms, but without ketoacidosis, the insulin requirements are less and the dose of regular insulin is only 0.1-0.2 unit/kg, every 6 -hours, before meals. For these children, this stage of management can be called "the phase of initial adjustment".

3. **Close observation:** Clinical and laboratory check up are essential to avoid insulin shock (hypoglycemia) or return to hyperglycemia treatment of infections, if present, is continued during this phase.

At the end of this stage, which usually takes 2-3 days, the patient is receiving average diet and is ready for the next phase.

Lifelong management

During the first few days of this long-term phase, the patient is kept in hospital for adjustment of insulin dosage and for education of parents and the child about the different aspects of management. Management during this stage includes four aspects; (1) insulin therapy, (2) nutritional therapy, (3) exercise adjustment and (4) emotional support. For details of therapy, see Practical Pediatric Therapy.

27 Chapter

Acute Suprarenal Failure

Diagnosis

Clinical manifestations

Vomiting
Dehydration, shock
Hypotonia, coma

Laboratory findings

Hypoglycemia
Hyponatremia
Hyperkalemia
Low cortisol level

Management

I.V. fluid therapy

Glucose 25% (2 ml/kg)
Shock therapy
Deficit therapy
Maintenance therapy

Replacement therapy

I.V. Dexamethazone
I.V. ACTH
I.V. Hydrocortisone

Acute suprarenal failure is an uncommon catastrophic event, which can lead to death if not recognized and urgently treated. The causes usually vary with age. Neonatal causes include congenital adrenal hyperplasia and perinatal adrenal hemorrhage. Waterhouse Friderichsen syndrome is an acute hemorrhage into the adrenals, which may occur at any age due to coagulopathy associated with fulminant sepsis. Meningococcemia and purpura is a classic example, which should suggest the diagnosis. Addisonian crisis is an episode of acute suprarenal failure in patients with Addison disease (chronic suprarenal insufficiency). In this case, pigmentation may be well evident on the face, hands, around genitalia, nipple and pressure areas.

Clinical and laboratory manifestations of acute suprarenal failure are related to acute mineralocorticoid and glucocorticoid deficiency.

Pathophysiological changes of acute suprarenal failure

Mineralocorticoid (aldosterone) deficiency

Loss of extracellular fluids: Dehydration, hypotension or frank shock.
Acid-base disturbance: Metabolic acidosis.
Electrolyte disturbance: Hyponatremia, hyperkalemia.

Glucocorticoid (cortisol) deficiency

Vomiting and abdominal pain.
Hypotonia and hypotension.
Hypoglycemia and may be convulsions.

- **Shock** in acute suprarenal failure is due to both mineralocorticoid and glucocorticoid deficiency. Therefore, it is not responsive to volume expansion and catecholamines unless glucocorticoids are used simultaneously.

- **Sudden withdrawal of steroid therapy**, especially after prolonged high dose therapy, may result in acute glucocorticoid deficiency but without mineralocorticoid deficiency.

DIAGNOSIS

The possibility of acute suprarenal failure should be considered in the following situations; (1) neonates with severe vomiting and dehydration, (2) severe infection with high fever and purpuric eruption, (3) shock not responding to volume expansion and catecholamines. Diagnosis depends on a combination of clinical and laboratory findings.

Diagnostic criteria of acute suprarenal failure

Clinical manifestations

Vomiting, abdominal pain.
Dehydration, shock (poor peripheral perfusion, hypotension).
Hypotonia, coma.

Laboratory findings

Hypoglycemia.
Hyponatremia, hyperkalemia, metabolic acidosis.
Low cortisol level (not essential in emergency situations).

MANAGEMENT

Once the diagnosis of acute suprarenal failure is suspected, immediate treatment should be started without waiting for laboratory confirmation of low cortisol level. It is important to remember that the emergency therapy has no serious effects if the diagnosis is wrong but, on the other hand, if the diagnosis is missed, the condition is rapidly fatal.

Emergency management of suspected acute suprarenal failure

I.V. fluid therapy

Immediate I.V. line and withdrawal of blood sample for investigations.
Glucose 25% (2 ml/kg) to correct hypoglycemia.
Shock therapy: 20 ml/kg of Ringer's lactate or saline. Repeat if necessary
Deficit therapy: 80-100 ml/kg of glucose 5% and saline (1:1) over 8 hours.
Maintenance therapy: Glucose 5% and saline (4:1) over 16 hours.
— Potassium chloride solution is only added when hyperkalemia is corrected.
— Sodium bicarbonate may be used to correct severe acidosis.

Replacement therapy

Dexamethasone: 0.2 mg/kg, I.V. single dose.
ACTH: 250 microgram, I.V. single dose (ACTH test).
Hydrocortisone: 5 mg/kg, I.V. every 6 hours for 2 days, then reduce to reach:
2 mg/kg/day, oral (maintenance replacement therapy).

- Normal serum cortisol level is 5-25 microgram/dl. Measurement is made before and after ACTH administration. Low resting level with no increase after ACTH indicates primary defect while low resting level with significant increase after ACTH indicates ACTH deficiency.



Section 6

Hematologic Emergencies

- Acute Blood Loss
- Acute Hemolytic Anemia
- Disseminated Intravascular Coagulation (DIC)
- Oncologic Emergencies

28

Chapter

Acute Blood Loss

Diagnosis

Volume of blood loss

- Class I (15% or less)
- Class II (20- 25%)
- Class III (30- 35%)
- Class IV (40- 50%)

Cause of blood loss

- Traumatic (trauma, surgery)
- Pathological

Management

Emergency management

- Oxygen therapy
- Volume expansion
- Sample for cross matching, investigations
- Whole blood transfusion

Specific measures

- Local measures to control bleeding
- Treatment of the cause

Acute blood loss (hemorrhage) can be traumatic or pathological, external or internal and mild or severe causing hypovolemic shock and hypoxic anemic encephalopathy.

DIAGNOSIS

Volume of blood loss

Emergency examination of children with acute blood loss should include respiratory rate, heart rate, blood pressure, capillary refill, mental status and urine output. Children can be then broadly classified as without hypovolemic shock or with hypovolemic shock. Clinical assessment of severity or, in other words, estimation of the blood volume loss is important to guide therapy. Pallor is evident in severe cases.

Clinical assessment of the acute blood volume loss

Class I: 15% or less acute blood volume loss

- Tachycardia only.

Class II: 20- 25% acute blood volume loss

- Tachycardia (above 150 breaths/minute).
 - Tachypnea (above 40 breaths/minute).
 - Prolonged capillary refill and hypotension.
- (Hypovolemic shock)

Class III: 30- 35% acute blood volume loss

- All above signs.
- Disturbed consciousness (lethargy, confusion).
- Oliguria (urine output less than 1 ml/kg/hour).

Class IV: 40-50% acute blood volume loss

- No palpable pulse.
- Coma (due to severe hypovolemic shock and hypoxic anemic encephalopathy).
- Normal blood volume is 75-80 ml/kg.

Cause of blood loss

Acute blood loss can be traumatic (trauma, surgery) or pathological (focal lesion, bleeding disorders). Full history, complete examination and some investigations are usually needed to reach an accurate diagnosis.

Causes and investigations of bleeding disorders

Causes

- Purpuras: Thrombocytopenic or nonthrombocytopenic.
- Coagulation defects: Inherited or acquired.
 - Inherited: Hemophilias and other coagulation defects.
 - Acquired: Vitamin K deficiency, liver failure, DIC.

Investigations

- Platelet count and platelet function.
- Thrombin, prothrombin and partial thromboplastin times.
- Fibrin and fibrin degradation products (FDPs).

MANAGEMENT

Management of acute blood loss includes into the following:

Emergency management

Mild transient blood loss necessitates no therapy. In moderate to severe cases, the following measures are indicated.

1. **Oxygen therapy:** It is essential to correct tissue hypoxia and to prevent hypoxic encephalopathy and hypoxic myocardial failure.
2. **Volume expansion:** 20 ml/kg of Ringer's lactate are urgently given I.V. over 10-15 minutes to correct hypovolemia until blood becomes available for transfusion. The amount can be repeated as necessary.
3. **Blood sample** is urgently withdrawn for cross-matching necessary for blood transfusion. Another sample is withdrawn for investigations.
4. **Whole blood transfusion:** It is indicated in class II, III and IV. The given volume depends on the estimated blood loss. It is 20 ml/kg in class II, 30 ml/kg in class III and 40 ml/kg in class IV. In case of ongoing blood loss, blood transfusion can be repeated as frequent as necessary.

Specific measures

1. **Local measures:** In traumatic cases or in bleeding due to focal lesion, local measures to control the bleeding site are essential.
2. **Specific measures:** In bleeding disorders, treatment of the causative disease and replacement therapy of the deficient factors are necessary.

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Chapter

Acute Hemolytic Anemia

Diagnosis

Diagnosis of hemolysis

Clinical manifestations
Laboratory findings

Cause of hemolysis

G6PD deficiency
Several other causes

Management

Emergency management

Oxygen therapy
Sample for investigations
Urgent red cell transfusion

Specific treatment

Treatment of the cause

Acute hemolysis is a condition characterized by rapid destruction of red cells in peripheral blood leading to acute anemia, unconjugated hyperbilirubinemia and hemoglobinuria. Rapid and accurate diagnosis is important because in most cases, urgent red cell transfusion is necessary and could be life-saving.

DIAGNOSIS

Diagnosis of acute hemolytic anemia should include diagnosis of acute hemolysis and identification of the causative disease.

Diagnosis of acute hemolysis

Diagnosis of acute hemolysis depends mainly on clinical manifestations, which can be confirmed by laboratory findings. In contrast to the situation of acute blood loss, the acute anemia of acute hemolysis is not associated with hypovolemia or hypovolemic shock.

Clinical and laboratory diagnosis of acute hemolysis

Clinical manifestations

Acute intense pallor due to acute hemolysis.
Acute jaundice due to unconjugated hyperbilirubinemia.
Dark urine (pink to red) due to hemoglobinuria.
Signs of acute hypoxia (tachycardia, tachypnea and altered consciousness) in severe cases.
Fever may also be present.

Laboratory confirmation

Acute anemia with fragmented or distorted red cells.
Reticulocytosis (above 5%) except with aplastic crisis (reticulocytopenia).
Unconjugated hyperbilirubinemia.
Hemoglobinemia and hemoglobinuria.

- Acute hemolysis should not be confused with acute hepatitis as in both conditions, acute jaundice and dark urine are present. In acute hemolysis, intense pallor is the most prominent feature, which is absent with acute hepatitis.

Cause of acute hemolysis

Identification of the cause of hemolysis requires careful clinical examination and some laboratory investigations. Clinical examination should include a search for purpura (hemolytic uremic syndrome or septicemia), splenomegaly (crisis of chronic hemolytic anemia or acute autoimmune hemolytic anemia) and manifestations of acute renal failure (hemolytic uremic syndrome). History of exposure to drugs (G6PD deficiency) and evaluation of the general condition (bad with septicemia) are also important. Laboratory investigations are usually chosen according to the most likely clinical diagnosis.

Possible laboratory investigations with acute hemolysis

CBC and CRP: In all cases (especially with suspected septicemia)
Evaluation of renal function: With suspected hemolytic uremic syndrome.
Coomb's test: With suspected autoimmune hemolytic anemia.
G6PD enzyme activity (3 weeks after the acute episode): With suspected G6PD deficiency.
Laboratory investigations of chronic hemolytic anemias.
Other investigations as blood film for malaria and serum ceruloplasmin.

1. **Hemolytic crisis of G6PD deficiency:** Glucose 6 phosphate dehydro-genase (G6PD) deficiency is an X-linked disease common in Mediterranean areas and is characterized by marked deficiency of the G6PD enzyme activity inside the red cells (about 5-10% of normal activity). Normally, the enzyme is responsible for the physiological protection of hemoglobin from oxidation on exposure to oxidant materials. With its deficiency, exposure to oxidant materials results in oxidation of hemoglobin to methemoglobin and its precipitation inside the red cells to form Heinz bodies. These red cells will be rapidly removed from the circulation leading to acute anemia.
 - Acute hemolytic crisis occurs on exposure to oxidant materials especially certain drugs and foods. Infections (bacterial or viral) may induce hemolysis in some patients.
 - Diagnosis is confirmed by the presence of the markedly reduced G6PD enzyme activity below 20 unit/ 10^{12} RBC (normal value is above 100 unit/ 10^{12} RBC). Estimation of G6PD enzymatic activity should be made after 3 weeks of acute hemolysis because immediately after hemolysis, the bone marrow releases immature forms of red cells with a higher enzymatic activity and a false normal results may be obtained.

Drugs and foods that induce hemolysis in G6PD deficiency

Drugs: Antipyretics as acetylsalicylic acid (aspirin) and metamizole (novalgine).
Antibiotics as chloramphenicol, nalidixic acid and furazolidone. Antimalarial drugs.
Sulphonamides (several antidiarrheal preparations contain sulphonamides).

Foods: Broad beans and its products are the most potent oxidants.
Fava beans (Favism) is also a potent oxidant.
Other beans as green beans and peas may also be responsible.

- In Egypt, the condition is usually discovered in late infancy as an acute hemolytic episode following ingestion of broad beans.

2. **Crises of chronic hemolytic anemias:** Several crises may occur in patients with chronic hemolytic anemias especially in response to infections.
 - a. **Aplastic crisis:** It is a transient episode of acute bone marrow failure, which usually occurs in response to infection. It leads to a severe and rapid life-threatening anemia because the shortened survival time of red cells is no longer compensated. It is a self-limited attack, which usually lasts 10 - 14 days. Diagnosis depends on the presence of acute severe anemia and reticulocytopenia (not reticulocytosis) in a known case of chronic hemolytic anemia. Bone marrow examination reveals diminished red cell precursors. Aplastic crisis of chronic hemolytic anemia should not be confused with aplastic anemia. Aplastic crisis is an acute anemia because it occurs in a hyperactive bone marrow of chronic hemolytic anemias while aplastic anemia is a chronic anemia because it occurs in a normal bone marrow.
 - b. **Hyperhemolytic crisis:** It is characterized by acute hemolytic episode with intense pallor, jaundice and dark urine (hemoglobinuria). Reticulocytic count is high (important differentiating point from aplastic crisis).
 - c. **Sequestration crisis:** It is an acute severe anemia caused by sudden pooling of large amount of blood into the liver and spleen. Clinically, liver and spleen are markedly enlarged and may be tender and manifestations of hypovolemic shock may be evident. Although sequestration crisis is not a hemolytic crisis, it should be considered in patients of chronic hemolytic anemia presenting with acute anemia.
 - d. **Vaso-occlusive (painful) crisis:** It is characterized by painful swellings of hands and feet (hand-foot syndrome) and painful swellings of large joints (see arthritis). It occurs mainly in sickle cell anemia. It is not associated with acute anemia but only mentioned here to be compared with other crises.
3. **Hemolytic uremic syndrome:** It is a syndrome of acute hemolytic anemia, acute renal failure, thrombocytopenia and distorted red cells. Clinically, acute intense pallor, hematuria, oliguria and purpura are usually present. Laboratory diagnosis depends on the presence of acute hemolysis, distorted red cells, thrombocytopenia and acute renal failure. The condition should be differentiated from bilateral renal vein thrombosis and septicemia because in these three conditions—acute hemolysis, acute renal failure and thrombocytopenia may coexist.

4. **Hemolytic anemia of infection:** Certain infections especially septicemia and malaria can produce direct destruction of the red cells by the organisms or their toxins. In these conditions, in addition to acute hemolysis, the clinical manifestations of the cause are usually evident. With septicemia, the patient is critically sick where thrombocytopenia and acute renal failure may also occur. Clinical and laboratory differentiation from hemolytic uremic syndrome and bilateral renal vein thrombosis is important. It is also important to remember that infections can also precipitate hemolysis in patients with G6PD deficiency or chronic hemolytic anemia.
5. **Acute autoimmune hemolytic anemia:** It occurs due to presence of abnormal antibodies produced by the patient and directed against his red cells. The illness is commonly preceded by a respiratory infection. Clinically, manifestations of acute hemolysis (intense pallor, jaundice, dark urine and may be fever) and marked splenomegaly are usually evident. Laboratory findings are characteristic and include marked reticulocytosis (about 50% of circulating red cells), spherocytosis, leukocytosis and strongly positive direct Coomb's test. Concomitant immune thrombocytopenia may be occasionally present (Evans syndrome). The illness responds to steroids and full recovery usually occurs within few months except in Evan syndrome where the condition may become chronic (i.e. thrombocytopenia is a bad prognostic sign).
6. **Metabolic acute hemolysis:** Rarely, acute hemolytic anemia can be caused by metabolic diseases especially erythrocytic porphyria and Wilson disease. When acute hemolysis and acute hepatitis coexist, Wilson disease should always be excluded.

MANAGEMENT

Oxygen therapy and **urgent red cell transfusion** (10 ml/kg) are the main lines of therapy. Volume expansion is not required as there is no hypovolemia.

Prevention of further hemolytic crises in G6PD is important. Antibiotic therapy in septicemia and treatment of acute renal failure in hemolytic uremic syndrome are important.

Disseminated Intravascular Coagulation (DIC)

30 Chapter

Diagnosis

Clinical manifestations

Precipitating illness
Bleeding, purpura
Necrotic skin patches

Laboratory diagnosis

Thrombocytopenia
Prolonged TT, PT, PTT
Fibrin degradation products (FDPs)

Management

Treatment of primary illness
Replacement therapy
Platelets
Plasma
Cryoprecipitate
Whole blood
Heparin therapy
Exchange transfusion

Disseminated intravascular coagulation (DIC) is a *hemostatic failure* characterized by consumption of platelets and some coagulation factors (1, 2, 5, 8) in a process of formation of minute intravascular clots. This leads to widespread hemorrhage secondary to thrombocytopenia and severe coagulation defect.

DIC usually occurs as a complication of another severe critical illness. Septicemia and shock are the main precipitating factors. With septicemia, DIC occurs due to several mechanisms including endotoxic effect, direct vascular damage, leukocyte activation, platelet injury and associated shock and vascular stasis. Advanced shock due to any reason can also lead to DIC as a one manifestation of multiple organ system failure (see shock). Other causes of DIC include severe dehydration (vascular stasis), severe head injury (release of thromboplastic substances) and malignant neoplasms as leukemia. Severe gastroenteritis with dehydration is an ideal situation for DIC to develop where sepsis, shock and dehydration coexist.

Hematological complications of septicemia

Acute hemolytic anemia: Due to direct destruction of red cells.
Consumptive thrombocytopenia: Due to direct destruction of platelets.
Disseminated intravascular coagulation: Due to consumption of platelets and coagulation factors.

DIAGNOSIS

Clinically, the patient is critically sick and the features of the precipitating disease are well evident (sepsis, shock, dehydration). The hematological manifestations of the disease include bleeding from puncture sites and surgical incisions, purpura (petechiae

and ecchymoses) and necrotic skin patches (characteristic of DIC). Internal hemorrhage (including intracranial hemorrhage) may occur due to thrombocytopenia and severe coagulation defect.

Laboratory diagnosis depends on the presence of (1) thrombocytopenia, (2) severe coagulation defect (prolonged thrombin, prothrombin and partial thromboplastin times) and (3) fibrin degradation products (FDPs) in the peripheral blood.

Prognosis is generally bad and it depends on the proper control of the precipitating factors and extension of internal hemorrhage.

Differential diagnosis of DIC

Other causes of thrombocytopenia in critically sick patients

Septicemia: Thrombocytopenia, \pm acute hemolytic anemia.

Hemolytic uremic syndrome: Thrombocytopenia, acute hemolytic anemia, ARF.

Bilateral renal vein thrombosis: Hematuria, flank masses.

Other causes of acquired coagulation defect

Liver disease: Deficient factors (1,2,5,7,9,10). Factor 8 is preserved.

Vitamin K deficiency: Deficient factors (2, 7, 9, 10).

MANAGEMENT

The best strategy for dealing with DIC is through prevention. Sepsis, shock, dehydration should be early detected and promptly corrected. For the already established cases, management includes treatment of the primary illness, replacement therapy, heparin therapy and exchange transfusion.

Management of DIC

Control of the primary illness

Interruption of the process of DIC by control of the precipitating factors.

Sepsis, shock, dehydration, acidosis and hypoxemia should be urgently corrected.

Replacement therapy

Platelet concentrates: 2 ml/kg (or one bag/5 kg), I.V. every 12-24 hours.

Fresh frozen plasma: 10 ml/kg, I.V. every 12-24 hours.

Cryoprecipitate: 5 ml/kg (or one bag/5 kg), every 12 hours.

Whole blood: 10-20 ml/kg, I.V. (to compensate for blood loss).

Vitamin K₁: 5-10 mg, I.V. every 24 hours.

Heparin therapy

Indicated when widespread thrombotic lesions are evident (purpura fulminans).

Heparin: 50-100 units/kg, I.V. every 4 hours.

Exchange transfusion

In neonates who cannot tolerate volume overload or when massive hemorrhage occurs.

It is useful through removal of toxins and addition of deficient factors.

31 Oncologic Emergencies

Chapter

Hematologic

Anemia
Thrombocytopenia
Neutropenia
Hyperleukocytosis
DIC
Hemorrhage

Metabolic

Tumor lysis syndrome
Hyperuricemia
Hyperkalemia
Hyperphosphatemia
Hyponatremia
Hypercalcemia

Other emergencies

Space-occupying lesions
Increased ICP
SVC syndrome
Spinal cord compression
Serious infections

Children with cancer may develop acute life-threatening conditions that necessitate rapid recognition and urgent therapy. These emergencies include hematologic disorders, metabolic disorders, space-occupying lesions and serious infections.

1. **Hematologic emergencies:** Pancytopenia due to bone marrow suppression or infiltration is common and necessitates replacement therapy with red cells, white cells and platelets. Acute blood loss due to thrombocytopenia or DIC necessitates whole blood transfusion. DIC may occur due to associated sepsis and hypotension tumor factors. Hyperleukocytosis (more than $50,000/\text{mm}^3$) may occur with leukemia and leads to thrombosis, pulmonary infiltrate or tumor Lysis syndrome. Exchange transfusion or leukapheresis may be effective and should be followed by chemotherapy.
2. **Metabolic emergencies:** Several metabolic disorders are common with cancer especially with therapy. These disorders include the following:
 - a. **Tumor lysis syndrome:** It is a syndrome of rapid release of intracellular metabolites (uric acid, potassium, phosphate) in quantities that exceed the excretory capacity of the kidney. It occurs most commonly in patients with large cell burden of tumors sensitive to chemotherapy as leukemia and lymphoma. The main metabolic disorders are:
 - i. **Hyperuricemia:** It occurs due to degradation of purines released from the fragmented tumor nuclei. Moderate hyperurecemia (10-15 mg/dl) leads to nonspecific symptoms as lethargy, nausea and vomiting. With higher levels (15-20 mg/dl or more), renal failure occurs. Treatment includes the following; (1) Allopurinol (50-100 mg/dose, oral, 3 times per day) to decrease uric acid production, (2) hydration to increase uric acid excretion by the kidney, (3) alkalanization with sodium bicarbonate

to increase urine solubility and (4) dialysis (peritoneal or hemodialysis) in case of renal failure or neurological manifestations as coma or convulsions.

ii. *Hyperkalemia*: It occurs due to tumor lysis, oliguric acute renal failure and excess potassium intake (stored blood or potassium containing medications). Clinically, cardiac arrhythmias (peaked T-wave, wide QRS) are the most serious manifestations, which may progress to asystole or ventricular fibrillation. Treatment includes the following; (1) stop potassium intake, (2) antagonising the cardiac effect (calcium gluconate), (3) mobilizing the potassium intracellularly (sodium bicarbonate or glucose/insulin therapy), and (4) removal of potassium from the body (dialysis). For details of therapy, see metabolic disorders and acute renal failure.

iii. *Hyperphosphatemia and hypocalcemia*: They occur due to tumor lysis and acute renal failure. Clinically, gangrenous skin patches and inflammation of eyes and joints occur due to precipitation of calcium phosphate in microvasculature. Hypocalcemic tetany may also occur. Treatment is by hydration, diuretics, aluminium hydroxide gel and dialysis (if phosphate level exceeds 10 mg/dl). Hypocalcemic tetany is treated with calcium gluconate 10% (1 ml/kg, slow I.V. over 10 minutes).

b. *Hyponatremia*: It is the commonest metabolic disorder in acute nonlymphocytic leukemia. It occurs due to saline depletion (vomiting) and inappropriate secretion of antidiuretic hormone. Treatment is by hypertonic saline solution 3% (see electrolyte disorders).

c. *Hypercalcemia*: It occurs in Hodgkin disease, non-Hodgkin lymphoma and osteolytic metastasis. Clinical manifestations and treatment depends on the level of serum calcium. With mild hypercalcemia (12-15 mg/dl), general weakness, nausea, vomiting and polyuria occur and treatment is mainly directed to correct dehydration and to provide oral phosphate (10 mg/kg/dose, twice daily). Severe hypercalcemia (level above 15 mg/dl) leads to severe vomiting, coma and serious bradyrhythmia. Treatment is by peritoneal dialysis or hemodialysis.

3. **Space-occupying lesions**: Several complications related to the tumor mass can occur and lead to acute life-threatening conditions.

a. *Increased intracranial pressure*: It occurs with primary or secondary brain tumors. Clinically, headache, vomiting, confusion and papilledema are usually present. In severe cases, coma and convulsions may occur. CT scan of the head or MRI is essential for diagnosis. In addition to radiotherapy and chemotherapy, corticosteroids and ventriculoperitoneal shunt are useful measures to reduce the elevated intracranial pressure.

b. *Superior vena cava syndrome*: It usually occurs in lymphoma due to compression of SVC or intracaval thrombosis. Clinically, distended neck veins, edema and plethora of the head and neck, conjunctival edema and proptosis are usually present. Tracheal compression leads to respiratory distress and cyanosis. Vocal

cord paralysis may also occur. Diagnosis is made by chest X-ray or CT scan of the chest (mediastinal mass), bone marrow examination and lymph node biopsy. Treatment is by corticosteroids, chemotherapy and radiotherapy.

- c. **Spinal cord compression:** It occurs due to extradural or intradural lesions as lymphoma, neuroblastoma or medulloblastoma. Clinically, back pain, motor weakness (symmetric or asymmetric) and sensory loss are usually present. Diagnosis is made by MRI of the spine and/or myelography. Corticosteroids, radiotherapy, chemotherapy and laminectomy are the main lines of therapy.

4. **Serious infections:** Children with malignancies have a significant risk to a variety of infections due to neutropenia, impaired T and B-cell functions, splenectomy (as in Hodgkin disease) and mechanical reasons (including catheters, invasive procedures). Two clinical presentations are common and deserve mentioning:

- a. **Fever in neutropenic patient:** It is mostly due to bacterial or fungal infections. Gram-negative organisms (as *E. coli*, *Klebsiella*, enterobacter, *Pseudomonas*) and staphylococcus aureus are the most common bacterial infections. Treatment should start with a triple regimen of an aminoglycoside (as amikacin), antipseudomonal penicillin (as piperacillin) and antistaphylococcal drugs (as cloxacillin). However, subsequent treatment should be guided by the results of culture-sensitivity studies. If the patient remains febrile, empirical antifungal therapy with fluconazole should be added.
- b. **Diffuse pulmonary infiltrate:** It is mostly due to pneumocystis carinii in up to 50% of cases. Other causative organisms are bacterial (*Staphylococcus aureus*, *Pseudomonas*), viral (cytomegalovirus) and fungal infections (candida). The infiltrate is caused by malignant infiltrate in only 5% of cases. Lung biopsy is the only reliable method for diagnosis. Treatment depends on the causative organism.



Section 7

Digestive Emergencies

- Severe Gastroenteritis
- Gastrointestinal Bleeding
- Acute Abdominal Pain

32 Chapter

Severe Gastroenteritis

Diagnosis

Diagnosis of gastroenteritis

Bacterial GE
Viral GE
Parasitic GE

Diagnosis of complications

Metabolic complications
Systemic complications

Management

I.V. fluid therapy

Shock therapy
Deficit therapy
Maintenance therapy

Antibiotic therapy

Treatment of complications

Gastroenteritis is a common worldwide problem. Five millions of children under the age of 5 years die every year with the complications of severe gastroenteritis. Most of these deaths occur in underdeveloped countries where nutritional deficiencies and environmental pollutions are common, and facilities for proper care are less available.

DIAGNOSIS

Diagnosis of gastroenteritis is clinical and depends on the presence of acute diarrhea with or without fever and vomiting. Accurate diagnosis should include assessment of severity (mild, moderate, severe), possible causative organism (bacterial, viral, parasitic) and the associated complications.

Diagnosis of gastroenteritis

Although accurate differentiation between bacterial, viral and parasitic gastroenteritis cannot be made except by stool analysis and stool culture, the cause can be suggested in most cases by considering the character of the stool and the associated findings especially fever.

- 1. Bacterial gastroenteritis:** The possibility of bacterial enteritis is considerable when the fever is above 38.5°C and the diarrhea is severe or bloody. The main 5 causative, organisms are *Shigella*, *Salmonella*, *E. coli*, *Campylobacter* and *Yersinia enterocolitica*. Other organisms as staphylococcus and *Pseudomonas* may be responsible during massive antibiotic therapy. The stool character is a useful guide in suggesting the causative organism. Accurate differentiation can be only made by stool culture. Leukocytosis and elevated CRP level are common laboratory findings.

2. **Viral gastroenteritis:** Fever is usually below 38°C and the diarrhea is usually watery and not severe. The possibility is higher in the following situations; (1) when there is preceding or associated viral respiratory infection, (2) when the diarrhea is occurring in winter season, (3) when more than one member of the family are simultaneously affected. Rotavirus is by far the most common causative agent. Other viruses as enteroviruses and adenovirus may be occasionally responsible.
3. **Parasitic enteritis:** Clinical manifestations depend on the causative agent. With *Giardia lamblia*, the diarrhea is usually watery, foul smelling, not severe and not associated with fever. The possibility becomes greater when diarrhea persists for more than 10 days (*giardia* is the most common cause of mild persistent watery diarrhea). With amoebiasis, diarrhea is commonly bloody but fever is absent (important differentiating point from bacterial gastroenteritis). Accurate diagnosis is made by stool analysis. Repeated stool analysis is important for the diagnosis of giardiasis because initial negative analysis does not exclude the possibility. It is important to remember that in parasitic enteritis, fever and vomiting are usually absent.

Diagnostic significance of the stool character in acute diarrhea

Acute watery diarrhea

E. coli (enterotoxigenic form): The commonest cause of bacterial watery diarrhea.

Shigella (diarrheal form): High fever and abdominal cramps are common.

Chorea: Should be considered in endemic areas.

Staphylococcal: Uncommon, in patients with prolonged antibiotic therapy.

Viral (rotavirus) diarrhea is not severe, transient, mainly in winter.

Giardia lamblia: Diarrhea is not severe, foul smelling, may persist, no fever

Postenteritis malabsorption (sugar intolerance and/or milk allergy): Should be considered when watery diarrhea appears after initial improvement and refeeding with milk.

Acute bloody diarrhea

Shigella (dysenteric form): High fever and abdominal cramps are common. Diarrhea is frequent and mainly consisting of small amounts of blood and mucus.

Campylobacter: Watery and offensive for 2 - 3 days, then profuse bloody diarrhea.

E. coli (enteroinvasive form): Watery, then bloody diarrhea.

Salmonella and *Yersinia enterocolitica* may be also the cause of bloody diarrhea.

Entamoeba histolytica: Diarrhea is usually not severe. No fever or vomiting.

Intussusception: It should always be excluded (see acute abdominal pain).

- Stool analysis is only useful for detection of parasites and for documentation of the presence of blood and mucus.
- Stool culture is the only way for identification of the causative bacterial agent.
- Leukocytosis and elevated CRP level are common with bacterial gastroenteritis
- Rotavirus can be only detected by electron microscopy of the stool.

Diagnosis of complications

Several complications are common with severe gastroenteritis and are responsible for the high morbidity and mortality. These complications are most common in infants with severe bacterial gastroenteritis. Dehydration, metabolic acidosis and hypovolemic shock are the most common. Convulsions may occur due to several causes but not due to CNS infection. DIC occurs in severe cases.

Complications of severe gastroenteritis

Metabolic complications

Dehydration: Due to severe diarrhea, persistent vomiting.
 Metabolic acidosis: Due to loss of alkalies and acute renal failure.
 Electrolyte disorders: Hyponatremia, hypernatremia, hypokalemia, hypocalcemia.
 Acute renal failure: Due to hypovolemia (prerenal failure).

Cardiovascular complications

Shock (circulatory failure): Hypovolemic (dehydration) and septic (gram-negative infection).

Neurologic complications

Convulsions: Febrile, toxic, metabolic, intracranial hemorrhage (DIC).
 Coma: Due to severe dehydration, severe acidosis, electrolyte disturbance.

Hematologic complications

Bleeding: DIC, hypoprothrombinemia, intussusception, renal vein thrombosis.

Digestive complications

Persistent diarrhea: Persistent infection, malabsorption, fasting.
 Malnutrition.

MANAGEMENT

Mild and moderate cases of gastroenteritis can be safely managed at home. Prevention of dehydration, dietetic management and symptomatic treatment (fever, vomiting) are the main lines of therapy. Follow-up and re-evaluation within few days is important to identify deteriorating cases requiring hospital management. Severe cases should be hospitalized, closely monitored and urgently managed.

Investigations in severe complicated gastroenteritis

To identify the causative organism

Stool analysis: For detection of parasites, blood and mucus.
 Stool culture: For detection of the causative bacterial agent.
 CBC and CRP: Leukocytosis and elevated CRP are common with bacterial infections.

To identify the complications

Blood gases: For diagnosis of metabolic acidosis.
 Serum electrolytes (Na, K, Ca): For detection of electrolyte disorders.
 Blood urea and creatinine: With suspected renal failure.
 Platelets, prothrombin time and fibrin degradation products: With suspected DIC.
 Abdominal X-ray and surgical consultation: With suspected intussusception.
 CT scan of the head: With suspected intracranial hemorrhage.

Management includes the following aspects:

1. **I.V. fluid therapy:** It is indicated for treatment of shock, correction of dehydration, reversal of prerenal failure and treatment of acid-base and electrolyte disorders.

I.V. fluid therapy of severe gastroenteritis and dehydration**Shock therapy (over maximum 1 hour)**

Ringers lactate or normal saline: 20 ml/kg.

May be given over 10-15 minutes and may be repeated in severe cases.

Deficit therapy (over 8 hours)**Amount given**

Mild dehydration: 40 ml/kg (or maintenance \times 0.4).

Moderate dehydration: 80 ml/kg (or maintenance \times 0.8).

Severe dehydration: 120 ml/kg (or maintenance \times 1.2).

Solutions used

Isonatremic dehydration: Glucose 5% + saline mixture 1:1.

Hyponatremic dehydration: Glucose 5% + saline mixture 1:1.

Hypernatremic dehydration: Glucose 5% + saline mixture 4:1.

(KCl solution 15% is added in amount of 1 ml for each 100 ml solution).

Maintenance therapy (over 15-16 hours)**Amount given**

100 ml/kg/day... for the first 10 kg body weight.

50 ml/kg/day added for each kg from 11-20 kg.

20 ml/kg/day... added for each kg above 20 kg.

e.g. a child 17kg needs $(10 \times 100) + (7 \times 50) = 1350$ ml/day.

Solutions used

Glucose 5% + saline mixture 4:1.

(KCl solution 15% is added in amount of 1 ml for each 100 ml solution).

- Glucose 5% + saline mixture can be replaced by Kadalex and saline mixture with no need of addition of KCl solution.
- In hypernatremic dehydration, undercorrection and slow correction are important to avoid brain edema and convulsions. Therefore, only 60% of the calculated deficit and 70% of the calculated maintenance are given over 24 hours. The simplest practical method is to ignore dehydration and to give maintenance solution in an amount of 130 ml/kg/day (see also hypernatremia).
- Symptomatic hyponatremia, hypernatremia and hypocalcemia should be corrected with the appropriate lines of therapy (see electrolyte disorders).
- Severe persistent metabolic acidosis after shock therapy should be corrected with sodium bicarbonate (see acid-base disorders).
- Severe hypokalemia can not be corrected over the first 24 hours because the concentration of potassium in solution should not exceed 35-40 mEq/litre.

During the next 24 hours, management depends on the clinical condition:

- If the patient is still dehydrated, deficit and maintenance therapy are repeated.
- If the patient is fully hydrated but the severe watery diarrhea is continuing, the maintenance therapy plus the expected losses are given over the next 24 hours.
- If the patient is fully hydrated and the diarrhea is improving, gradual oral intake is allowed where half the maintenance requirements are given I.V. and the other half is given orally in the form of oral rehydration solution and other cold fluids. Over the next few days gradual refeeding is allowed as those of home management.

2. **Antibiotic therapy:** Parenteral antibiotic therapy is indicated in patients with high persistent fever especially when associated with early septic shock or laboratory manifestations suggesting severe bacterial infection (leukocytosis, bandemia, elevated CRP). Ampicillin (100 mg/kg/day), chloramphenicol (100 mg/kg/day) or cefotaxime (100 mg/kg/day) is given I.V. in 3-4 divided doses. An aminoglycoside as gentamicin or tobramycin (5 mg/kg/day, I.V. in 2-3 divided doses) or amikacin (15 mg/kg/day, I.V. in 2-3 divided doses) may be added in severe cases. Therapy is continued for at least 5 days.
3. **Treatment of complications:** Renal failure, convulsions and bleeding are common complications of severe cases:
 - a. **Renal failure:** Organic renal failure due to acute tubular necrosis should be considered if the patient did not pass urine after shock therapy with Ringer's lactate. The deficit therapy is then given without adding the potassium chloride solution. Failure of urination within 4 hours of initiation of deficit therapy is an indication to evaluate the renal function and to try induction of diuresis with drugs (see acute renal failure).
 - b. **Convulsions:** Initial control with diazepam (0.5 mg/kg, slow I.V.) is indicated. Metabolic causes as hypocalcemia or hyponatremia should be corrected. Convulsions with bleeding should suggest intracranial hemorrhage due to DIC.
 - c. **Bleeding:** Hypoprothrombinemia due to prolonged fasting and vitamin K deficiency is corrected by vitamin K₁ injection (5-10 mg, I.V.). Successful management of DIC depends on the prompt control of the precipitating factors especially septicemia, shock acidosis and dehydration. Platelet transfusion, fresh frozen plasma transfusion and whole blood transfusion should be considered. Exchange transfusion, if possible, may be useful.
 - d. **Persistent diarrhea:** In extremely severe cases with severe persistent watery diarrhea for several days, total parenteral nutrition should be considered to provide the nutritional requirements and to allow for regeneration of the injured intestinal mucosa.

33 Gastrointestinal Bleeding

Chapter

Hematemesis

Acute gastric ulceration
Esophageal varices

Bleeding per rectum

Acute bloody diarrhea
Intussusception, volvulus

Gastrointestinal bleeding is a common problem in pediatric practice. According to the site of external loss, bleeding can be classified into hematemesis and bleeding per rectum. Although most cases are due to local gastrointestinal lesions, blood diseases (purpuras and coagulation defects) should be routinely excluded especially when bleeding from other orifices (epistaxis, hematuria) and/or cutaneous manifestations (purpura, bruises) are also present.

Hematemesis

Hematemesis (or vomiting of blood) occurs with swallowed blood or when bleeding originates from the esophagus, stomach or duodenum. Clinical assessment of the amount of blood loss is important and it depends on:

1. **Color of blood:** Darkened altered blood (coffee ground) usually indicates a mild to moderate bleeding while fresh red blood is usually associated with massive bleeding. Coffee ground color results from the effect of the gastric juice on the blood.
2. **Effect of bleeding:** Mild bleeding is usually not associated with hematological or cardiovascular effects. Massive bleeding is associated with acute anemia (intense pallor) and may be hypovolemic shock (see acute blood loss).

Acute gastric ulceration (Stress ulcers)

The condition is commonly seen in critically sick patients. Severe gastroenteritis and dehydration, septicemia, shock, burns and head trauma are the main causes. Coffee ground vomiting is the only finding and no bleeding from other areas. DIC should be excluded. Treatment includes the following aspects:

1. Repeated gastric lavage with ice-cold saline.
2. Administration of antacid (5-10 ml), 3-4 times/day, oral.
3. Cimetidine may also be given oral or I.V. in a dose of 20-40 mg/kg/day in 3-4 divided doses (Tagamol syrup, 200 mg/5 ml or Tagamet amp. 200 mg/2 ml).
The condition usually subsides within 1-2 days.

Esophageal varices

Esophageal varices secondary to portal hypertension is the most important cause of spontaneous massive hematemesis. Abdominal examination is important and it may reveal splenomegaly, hepatomegaly or hepatosplenomegaly. Ascites is a sign of advanced disease. Endoscopic examination of the lower esophagus is essential for diagnosis and grading of varices. Treatment is both medical and surgical.

1. Emergency medical treatment: It includes the emergency measures necessary to control the bleeding episode:

1. Oxygen therapy and Ringer's lactate infusion until blood is available.
2. Repeated nasogastric aspiration of blood to assess the amount and rate of blood loss.
3. Urgent whole blood transfusion in an amount depending on the estimated acute blood volume loss (20 ml/kg, 30 ml/kg, 40 ml/kg).

Fortunately, most cases respond to the above measures and bleeding stops spontaneously. When bleeding continues, tamponade using a Sungstaken-Blakemore tube may be required.

2. Surgical treatment: Endoscopic injection of sclerosing material into the esophageal dilated veins may be tried. Surgical shunting operation is usually required to control portal hypertension.

Bleeding per rectum

Bleeding per rectum is a common form of gastrointestinal hemorrhage. The color of blood may provide a diagnostic clue to the site of bleeding. Passage of fresh bright red blood (hematochezia) usually indicates that the site of bleeding is below the distal ileum. However, massive hemorrhage above the distal ileum may also lead to hematochezia. Passage of blackened tarry stool (melena) indicates an origin above the distal ileum but it may also accompany hematemesis or lesions in the esophagus and stomach.

Acute bleeding per rectum is caused by acute bloody diarrhea or acute intestinal obstruction. Although the volume of blood loss is usually not life-threatening, the underlying pathology is serious and necessitates urgent intervention.

Acute bloody diarrhea

It is by far the most common cause of bleeding per rectum. The condition can be bacterial (*Shigella*, *Salmonella*, *E. coli*, *Campylobacter* or *Yersenia enterocolica*) or parasitic (amoebic dysentery). With bacterial enteritis, high fever and vomiting are commonly associated findings while in amoebic dysentery these findings are usually absent. Toxic convulsions (shigellosis or salmonellosis) may occur with bacterial enteritis. Diagnosis is mainly clinical and can be confirmed by stool analysis and stool culture. Leukocytosis and elevated CRP are common with bacterial enteritis.

With bacterial enteritis, antibiotic therapy is indicated especially when associated with high fever. Amoebic dysentery necessitates therapy with antiamoebic drugs (see Practical Pediatric Therapy).

Acute intestinal obstruction

Intussusception should always be considered and excluded in every case of acute bleeding per rectum especially in infants around the age of 6 months. It is characterized by sudden onset of paroxysmal severe abdominal pain, vomiting and passage of stool containing blood and mucus (red currant jelly stool). Abdominal examination may reveal an abdominal mass in the right upper quadrant. Rectal examination is essential and the finger is usually withdrawn covered with blood and mucus. It should be remembered that intussusception may also occur as a complication of gastroenteritis, and presence of diarrhea does not exclude the possibility. With clinical suspicion, urgent surgical consultation is necessary. If the diagnosis is delayed, intestinal ischemia and gangrene will occur. In early cases, simple reduction is the rule while in late cases, resection anastomosis is almost necessary (see also acute abdominal pain).

Volvulus may also lead to bleeding per rectum but this is usually a late finding. The early manifestations are vomiting, abdominal pain and abdominal distension. Early diagnosis and surgical reduction are important.

34

Chapter

Acute Abdominal Pain

Acute abdominal infections

Streptococcal pharyngitis
Early gastroenteritis
Early hepatitis
Acute appendicitis
Acute pyelonephritis
Acute pancreatitis
Acute peritonitis

Acute medical conditions

Henoch-Schonlein vasculitis
Right lower lobe pneumonia
Acute rheumatic fever
Diabetic ketoacidosis
Splenic infarction
Drug intoxication
Acute hepatic porphyria

Acute intestinal obstruction

Incarcerated inguinal hernia
Intussusception
Volvulus
Postoperative adhesions
Impacted fecal masses
Round worm masses
Acute peritonitis

Acute abdominal pain is a common presentation in pediatric practice, which can be caused by acute abdominal infections, acute medical conditions or acute intestinal obstruction. Causes can also be classified as medical (most infections and acute medical conditions) and surgical (acute appendicitis and acute intestinal obstruction). Acute abdominal pain should not be confused with recurrent abdominal pain, which is caused by dysfunctional or organic causes (see Pediatric Clinical Diagnosis).

DIAGNOSIS

Proper history and careful examination are necessary to reach a diagnosis. Investigations are usually directed according to the most likely clinical diagnosis. When a surgical emergency is suspected, immediate surgical consultation is necessary.

1. **Acute abdominal infections:** The clinical triad of fever, vomiting and abdominal pain should suggest the following possibilities:

- a. ***Streptococcal pharyngitis:*** Throat examination is important in every case of acute abdominal pain. With streptococcal pharyngitis, abdominal pain is caused by the commonly associated mesenteric adenitis.
- b. ***Early gastroenteritis:*** Fever, vomiting and abdominal pain may be the initial manifestations of gastroenteritis. Diarrhea usually appears within 24 hours.
- c. ***Early hepatitis:*** Anorexia, mild fever, vomiting and abdominal pain should suggest early or preicteric hepatitis. Inspection of the urine for dark coloration (bilirubinuria) is an important simple test. Jaundice usually appears after 4 - 6 days and liver becomes enlarged and tender.
- d. ***Acute appendicitis:*** It should be considered in every case of acute abdominal pain in children. The pain is usually not severe and abdominal examination

reveals a tender right iliac fossa. When the abdominal pain is severe, the patient is probably not having acute appendicitis. Leukocytosis is an important confirmatory finding. In equivocal cases, re-evaluation after 6 hours is helpful. In true appendicitis, these 6 hours are sufficient to clarify the picture and diagnostic signs become well evident. When the diagnosis is delayed more than 36 hours, the risk of perforation and peritonitis is great.

- e. **Acute pyelonephritis:** High fever with rigors and abdominal pain should suggest the diagnosis. Tenderness over the loin may be elicited.
 - f. **Acute pancreatitis:** Fever, persistent vomiting and epigastric pain should suggest the diagnosis. The pain and vomiting usually increase during the first 2 days and the patient may require hospitalization. Diagnosis is confirmed by the elevated serum amylase level. Abdominal ultrasound is also very useful in demonstrating pancreatic enlargement, edema or abscesses. Viral infections especially mumps are the most common causes. Drugs (as diuretics, corticosteroids, paracetamol, sulfonamides and valproic acid) and blunt abdominal trauma are also common causes.
 - g. **Acute peritonitis:** Acute bacterial infection of the peritoneum can be primary or secondary. Acute primary peritonitis occurs in children with ascites due to nephrosis or cirrhosis and the infection is acquired through bacteremia or septicemia. The main invading organisms are *Pneumococci*, *Streptococci* and *E. coli*. Acute secondary peritonitis occurs through rupture of an intra-abdominal viscus as with neglected appendicitis, incarcerated hernia, intussusception or volvulus. The invading organisms are the normal aerobic and anaerobic flora of the gastrointestinal tract. Clinically, fever, vomiting and diffuse abdominal pain are the initial presentations. Abdominal examination reveals a diffuse generalized tenderness with abdominal wall rigidity. With a perforated viscus, the patient looks seriously sick with toxic look, high fever and shock-like state. Polymorphonuclear leukocytosis is usually present and abdominal X-ray reveals functional (ileus) or mechanical intestinal obstruction. With a perforated viscus, pneumoperitoneum can also be demonstrated (see Basic Pediatric Radiology).
2. **Acute medical conditions:** Abdominal pain may accompany several other medical conditions. With Henoch-Schonlein vasculitis, abdominal pain and bleeding per rectum may occur but diagnosis is mainly based on the characteristic purpuric eruption. Right lower lobe pneumonia may be accompanied with referred abdominal pain. With diabetic ketoacidosis, abdominal pain and vomiting are common but polyuria, dehydration, acidosis and altered consciousness are the main presenting features. Acute rheumatic fever may be accompanied with acute abdominal pain. Splenic infarction is rare but should be considered when abdominal pain is associated with left hypochondrial tenderness. Acute drug intoxication should also be considered. Acute hepatic porphyria is very rare below the age of 10 years.
 3. **Acute intestinal obstruction:** Persistent vomiting with constipation or abdominal distension should raise the possibility. Greenish bile-stained vomitus is a definite

sign of obstruction. With mechanical intestinal obstruction, colicky periumbilical pain is usually present and bowel sounds are also present (with functional obstructions both abdominal pain and bowel sounds are absent). The most important causes of mechanical obstruction are:

- a. **Incarcerated inguinal hernia:** Examination of hernial orifices and scrotum should be a routine step in every case of acute abdomen. Failure of reduction of an inguinal hernia is a surgical emergency.
- b. **Intussusception:** It is the most common cause of intestinal obstruction between 3 months and 3 years with a peak incidence around the age of 6 months. The cause is unknown in most cases but occasionally it complicates gastroenteritis. The illness starts suddenly with severe paroxysmal colicky abdominal pain that recurs at frequent intervals and is accompanied with loud crying. Initially, the infant looks well and plays normally between the attacks. Vomiting occurs in most cases and is usually more frequent early. Within 12 - 24 hours of onset, most patients pass stool containing blood and mucus (red currant jelly stools). At this point, the condition may be misdiagnosed as gastroenteritis with bloody diarrhea but absence of fever and the sudden onset of abdominal pain in an otherwise normal infant should suggest the diagnosis. Abdominal examination reveals a sausage-shaped mass, mostly in the right upper quadrant, in 70% of cases. The mass is better felt with bimanual abdominal and rectal examination. The presence of bloody mucus on the finger as it is withdrawn after rectal examination supports the diagnosis of intussusception. If the condition is not diagnosed early (during the first day or two), the infant will pass into a shock-like state with bile-stained vomiting, abdominal distension and high fever secondary to intestinal ischemia and gangrene. Plain X-ray of the abdomen may be useful and barium is occasionally needed (see Basic Pediatric Radiology). In early cases, simple reduction is the rule. In late cases, resection anastomosis is almost necessary.
- c. **Volvulus:** The sudden appearance of vomiting, abdominal pain and abdominal distension should suggest the diagnosis. If the condition is not diagnosed early, bowel gangrene and bleeding per rectum occur. The illness is differentiated from intussusception by the early appearance of distension and the late appearance of bleeding. In intussusception the reverse occurs (bleeding is early and distension is late).
- d. **Other causes:** Acute intestinal obstruction may occur with several other conditions. Intestinal obstruction following abdominal surgery should suggest postoperative ileus, postoperative acute peritonitis or postoperative adhesions. Acute obstruction with a palpable abdominal mass may suggest an impacted fecal masses (sausage-shaped masses in the left lower quadrant), masses of round worms, tumor mass or mesenteric cyst. Acute peritonitis can lead to functional or mechanical obstruction (see above).



Section 8

Serious Infections

- Serious Focal Infections
- Fulminant Sepsis or Septicemia

35 Chapter

Serious Focal Infections

Diagnosis

Respiratory infections
Cardiac infections
Neurologic infections
Abdominal infections
Skeletal infections

Management

System support

Respiratory support
Cardiovascular support
Neurologic support

Parenteral antibiotic therapy

Infections are by far the most common cause of short febrile illness in children. It is clinically useful to classify infections into focal infections (simple infections, serious infections) and fever without a focus or simple fever (viremia, bacteremia, septicemia).

High fever or hyperpyrexia should suggest serious bacterial infection (especially serious focal infections) or septicemia. Clinical evaluation should be first directed to search for a focus of infection. It is important to differentiate between simple infections, which are mostly self-limited and serious infections, which are life-threatening and need urgent recognition and prompt aggressive management.

Classification of focal infections

Simple focal infections

Respiratory: Nasopharyngitis, otitis media, sinusitis, tonsillitis, bronchitis.
Digestive: Stomatitis, simple gastroenteritis, hepatitis.
Cutaneous: Cellulitis, abscess.

Serious focal infections

Respiratory : Acute epiglottitis: Severe upper airway obstruction (stridor, \pm cyanosis).
Bacterial pneumonia: Respiratory distress, focal chest signs.

Cardiac : Acute myocarditis: Congestive heart failure.
Purulent pericarditis: Chest pain, dyspnea, tachycardia, cardiac tamponade.

Neurologic : Bacterial meningitis: Disturbed consciousness, convulsions, meningeal irritation.

Viral encephalitis: Disturbed consciousness, convulsions.

Abdominal : Severe gastroenteritis and dehydration.
Acute peritonitis: Abdominal distension, generalized tenderness.
Acute pancreatitis: Fever, persistent vomiting, epigastric pain.
Acute pyelonephritis: High fever, loin tenderness.

Fulminant hepatitis: Progressive jaundice, bleeding, coma.

Skeletal : Osteomyelitis or arthritis: Focal tenderness, swelling, and limitation of movements.

DIAGNOSIS

Diagnosis of serious focal infections depends mainly on the characteristic clinical manifestations. Laboratory investigations and other diagnostic procedures are usually directed according to the clinical diagnosis. High fever or hyperpyrexia should always suggest a bacterial infection. Leukocytosis, bandemia and elevated CRP are important confirmatory findings. Identification of the causative organism depends on the appropriate cultures.

Complications of serious focal infections

System failure

Respiratory failure: With severe epiglottitis, severe pneumonia.
Acute congestive heart failure: With severe myocarditis.
Obstructive shock: With severe purulent pericarditis (tamponade).
Hypovolemic shock: With severe gastroenteritis and dehydration.
Central neurologic failure: With meningitis or encephalitis.
Acute hepatic failure: With fulminant hepatitis.
Acute intestinal obstruction: With acute peritonitis.

Secondary septicemia

Septic shock and multiple organ system failure (MOSF).

MANAGEMENT

Children with serious focal infections should be immediately hospitalized preferably in an intensive care unit. Frequent clinical and laboratory monitoring of system functions is essential. Management includes the following aspects:

System support

Nonspecific support of the potential or actual failing system is essential. As the rule with any emergency, care of the airway, breathing and circulation comes first.

Antibiotic therapy

With serious focal bacterial infections, immediate parenteral antibiotic therapy should be started without waiting for laboratory confirmation. The initial antibiotic therapy is empirical and usually based on the clinical diagnosis. Subsequent change in antibiotic therapy depends on the clinical response and the results of culture-sensitivity studies. Duration of therapy depends on the diagnosis.

1. **Acute epiglottitis:** A broad-spectrum penicillin as ampicillin or amoxicillin (100 mg/kg/day, I.V., in 3-4 divided doses) is a reasonable initial therapy. Other choices are newer drugs as sultamicillin or co-amoxiclav or a third generation cephalosporin as cefotaxime (50-100 mg/kg/day, in 2-3 divided doses). Duration of therapy is usually for 5-7 days.
2. **Bacterial pneumonia:** A combination of broad-spectrum penicillin (as ampicillin or amoxicillin) and an aminoglycoside (as gentamicin, tobramycin, netilmicin or amikacin) is an initial reasonable combination. In severe cases of bronchopneumonia,

a third generation cephalosporin as cefotaxime (100 mg/kg/day) can be added. In case of staphylococcal pneumonia, a penicillinase resistant penicillin as cloxacillin should be used. Recently, vancomycin (40-60 mg/kg/day, I.V. in 3-4 divided doses) is considered as the drug of choice of methicillin-resistant staphylococci. The available preparation is vancocin vial (0.5 gm). When the possibility of pseudomonas infection is standing, antipseudomonal penicillin as piperacillin should be used. Duration of therapy should be for at least 10 days.

3. **Acute purulent pericarditis:** An initial therapy with 3 drugs (crystalline penicillin, cloxacillin and gentamicin) is recommended. Therapy should be guided by the results of culture-sensitivity studies. Vancomycin is the drug of choice for methicillin resistant staphylococcus aureus (MRSA). Duration of therapy is 3-4 weeks.
4. **Bacterial meningitis:** A third generation cephalosporin as cefotaxime (200 mg/kg/day), ceftriazone (100 mg/kg/day) or ceftazidime (100 mg/kg/day) is currently considered as the initial treatment of choice. Ampicillin (200 mg/kg/day... I.V.) may be also added. The use of chloramphenicol in bacterial meningitis (100 mg/kg/day) should be limited to patients who are sensitive to cephalosporins. New drugs of carbapenem group as imipenem or meropenem can be used in a dose of 60-100 mg /kg/day. Duration of therapy is 2-3 weeks.
5. **Bacterial gastroenteritis:** Ampicillin (100 mg/kg/day), chloramphenicol (100 mg/kg/day) or cefotaxime (100 mg/kg/day) can be used in 3-4 divided doses. An aminoglycoside as gentamicin or tobramycin (5 mg/kg/day, I.V. in 2-3 divided doses) may be added in severe cases. Duration of therapy is at least 5 days.
6. **Peritonitis:** A combination of a third generation cephalosporin (as cefotaxime) and an aminoglycoside (as amikacin) is an initial reasonable combination. Metronidazole (7.5 mg/kg/dose, I.V., every 12 hours) may be added to control anaerobic infections. Clindamycin, if available, can be used instead of metronidazole in a dose of 20-40 mg/kg/day... I.V. in 2 divided doses. Available preparation is Dalacin C amp. (300 mg). Duration of therapy is 2-3 weeks. New drugs as imipenem or meropenem can be used in a dose of 60-100 mg /kg/day.
7. **Acute pyelonephritis:** An aminoglycoside as gentamycin (3 mg/kg/day), tobramycin (3 mg/kg/day) or amikacin (10 mg/kg/day) can be used in 2 divided doses. A second or third generation cephalosporin as cefuroxime or cefotaxime (50-100 mg/kg/day, in 2 divided doses) is an alternative. Duration of therapy is 10-14 days.
8. **Osteomyelitis and septic arthritis:** A second or third generation cephalo-sporin as cefuroxime or cefotaxime (100-150 mg/kg/day) can be used. A combination of antistaphylococcal penicillin (as cloxacillin) and chloramphenicol is an alternative. Duration of therapy is 3-6 weeks. In cases of osteomyelitis, parenteral antibiotic therapy may be followed by oral antibiotics for 2-4 months.

36 Chapter

Fulminant Sepsis or Septicemia

Diagnosis

Clinical diagnosis

Clinical stages
Complications

Laboratory findings

Inflammatory response
Causative organisms

Management

System support

Cardiovascular support
Other system support

Antibiotic therapy

Other lines of therapy

Fulminant sepsis or septicemia is a clinical syndrome caused by a serious infection and characterized by systemic inflammatory response (SIR), which may progress to septic shock and multiple organ system failure (MOSF). The infection can be community-acquired or hospital-acquired (nosocomial infection) and can occur in immunocompetent individuals or immunocompromised patients. The main risk factors of nosocomial infections are endotracheal intubation, central venous lines, instrumentation and critical illnesses.

Causes, types and pathophysiological changes of septicemia

Causative organisms

Bacterial: *Staphylococcus aureus*, *Pseudomonas*, *Klebsiella*, *Enterobacter*, *E. coli*, *Hemophilus influenza*, *Meningococci*, *Streptococci*.

Viral: Cytomegalovirus, other viruses.

Fungal: *Candida albicans*.

Types of septicemia

Primary septicemia: Sepsis without a focus of localization.

Secondary septicemia: Sepsis due to extension from a focal infection.

Endogenous septicemia: Due to gut translocation of bacteria in advanced shock.

Pathophysiological changes or stages of severity

I. Sepsis and Systemic inflammatory response syndrome (SIRS).

II. Severe sepsis.

III. Early septic shock (warm shock).

IV. Late septic shock (cold shock).

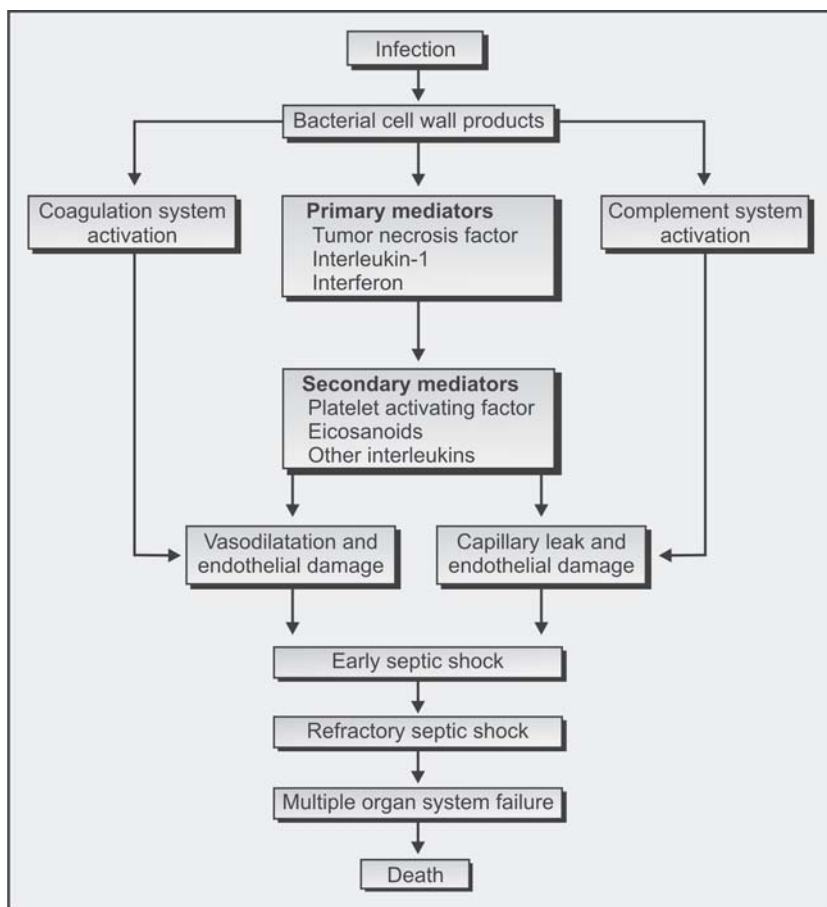
V. Multiple organ system failure (MOSF).

- **Systemic inflammatory response syndrome (SIRS)** occurs due to the release of endotoxins and other bacterial cell wall products which result in widespread

inflammatory response and release of different harmful mediators from capillary endothelium, leukocytes, platelets, complement and coagulation system. These mediators result in endothelial damage, capillary leak and vasodilatation.

- **Early septic shock** is a distributive shock characterized by vascular dilatation and relative hypovolemia. Because of absence of peripheral hypoperfusion, it is called a (warm shock).
- **Late or refractory septic shock** is a cardiogenic shock characterized by myocardial dysfunction, hypotension and peripheral hypoperfusion (cold shock).

Pathophysiological changes of septicemia



DIAGNOSIS

It should be emphasized that the diagnosis of sepsis is a clinical diagnosis based on actual presence or a high suspicion of infection. In addition, identification or isolation of the causative organism is not necessary for diagnosis.

Clinical diagnosis

Clinical manifestations of sepsis can be divided into 5 progressive stages (see below). *Early manifestations* include fever or hyperpyrexia, vomiting, toxic look, tachycardia and tachypnea. Cutaneous manifestations as purpura (petechiae or ecchymoses) should suggest a serious bacterial infection especially meningococcemia or hemophilus influenza type b. In secondary septicemia, the clinical manifestations of the causative focal infection (pneumonia, meningitis, pyelonephritis) may be well evident. *Late manifestations* include shock and multiple organ system failure. Symmetric peripheral gangrene (purpura fulminans) and focal serious infections (meningitis, pneumonia, peritonitis, osteomyelitis, arthritis) may also occur.

Clinical progression of sepsis to septic shock and MOSF

I. Sepsis and systemic inflammatory response syndrome (SIRS)

Clinical manifestations of infection.

Fever or hypothermia.

Tachycardia and tachypnea.

Bandemia (above 10%), leukocytosis or leukopenia, elevated ESR and CRP.

II. Severe sepsis

Clinical manifestations of sepsis plus one or more of the following four:

Acute mental changes, oliguria, lactic acidosis or hypoxemia.

III. Early septic shock

Clinical manifestations of severe sepsis.

Hypotension or poor peripheral perfusion that responds rapidly to I.V. fluids.

Peripheral hypoperfusion is usually absent during this stage (warm shock).

IV. Late or refractory septic shock

Clinical manifestations of severe sepsis.

Hypotension or poor peripheral perfusion refractory to I.V. fluids (for more than 1 hour).

Peripheral hypoperfusion is marked during this stage (cold shock).

Inotropic drug support is necessary to improve myocardial contractility.

V. Multiple organ system failure (MOSF)

More than one of the following five:

Disseminated intravascular coagulation (DIC).

Adult respiratory distress syndrome (ARDS).

Acute renal failure (ARF).

Acute hepatic failure (AHF).

Acute CNS dysfunction (toxic encephalopathy).

Mortality rate is very high during this stage.

Laboratory findings

Laboratory investigations of septicemia have three objectives, (1) to document the presence of systemic inflammatory response, which is highly suggestive of bacterial infection, (2) to detect complications related to different systems, and (3) to identify the causative organism. It is important to re-emphasize that identification or isolation of the causative organism is not necessary for diagnosis. Only 45% of cases have positive cultures.

Laboratory findings in septicemia

Systemic inflammatory response suggesting bacterial infection

Polymorphonuclear leukocytosis (above 15,000 cells/mm³) or leukopenia.
 Bandemia (above 10%) or band/total neutrophil ratio above 0.2.
 Toxic granulations in neutrophils.
 ESR above 20 mm/first hour.
 CRP above 20 mg/litre.

Laboratory manifestations of system affection

Blood gases: Hypoxemia and metabolic acidosis.
 CBC: Acute hemolytic anemia, consumptive thrombocytopenia.
 Coagulation mechanism: Prolonged prothrombin time, PTT, FDPs (DIC).
 Renal function: Elevated blood urea and serum creatinine.
 Hepatic function: Elevated serum bilirubin and transferases, reduced serum albumin.

Identification of the causative organism

Blood culture: Aerobic and anaerobic bacteria, fungi.
 Urine culture.
 CSF culture.
 Culture of tracheal aspirate.
 Culture of wounds.
 Culture of tip of endotracheal tube, tip of central catheter.

MANAGEMENT

Patients with fulminant sepsis should be immediately hospitalized, closely monitored and investigated (see above). Prompt management includes the following aspects:

Multisystem support

Oxygen therapy is important to prevent tissue hypoxia. Urgent cardiovascular support to prevent vital tissue hypoperfusion and multiple organ system failure is essential. Preload augmentation with volume expanders (20 ml/kg of Ringers lactate) is initially tried and may be repeated. Failure of response to volume expansion indicates a late septic shock (cardiogenic shock) and inotropic drug support (dopamine and/or dobutamine infusion) becomes necessary. Afterload reducing agents may be tried in refractory cases (see shock).

Other system support is also indicated if one or more systems are potentially or actually failing. Adult respiratory distress syndrome necessitates positive pressure support (CPAP or mechanical ventilation) and hematological manifestations of sepsis (acute hemolysis, thrombocytopenia, DIC) should be corrected by the appropriate measures. Acute renal failure or acute hepatic failure, if present, should be urgently managed. Neurological dysfunction (coma, convulsions, increased intracranial pressure) should also be dealt with.

Parenteral antibiotic therapy

- **Initial therapy:** Initial parenteral combined therapy with a broad-spectrum penicillin as ampicillin (100 mg/kg/day) and an aminoglycoside as gentamicin

(6 mg/kg/day) is satisfactory. Ampicillin can be substituted with other broad-spectrum penicillins with extended activity (as sultamicillin or co-amoxiclav) or with antipseudomonal activity (as piperacillin), and gentamicin can also be substituted with other aminoglycosides as tobramycin or amikacin. In severe cases, a third generation cephalosporin as cefotaxime (100-150 mg/kg/day) can be added. Newer drugs as imipenem or meropenem can be used I.V. in a dose of 60-100 mg/kg/day. When the possibility of anaerobic infection is considerable, metronidazole (7.5 mg/kg/dose, I.V. every 12 hours) can be used.

- **Subsequent change:** Subsequent change of antibiotic therapy can be made according to the clinical response and the results of culture-sensitivity studies. Ceftazidime (100 mg/kg/day, I.V. in 2 divided doses) is the drug of choice for pseudomonas infection, and vancomycin (40-60 mg/kg/day, I.V. in 3-4 divided doses) is the drug of choice for methicillin-resistant staphylococcus aureus (MRSA).
- **Duration:** The minimum duration of antibiotic therapy is two weeks. Duration can be extended in presence of unresolved focal infection as osteomyelitis or septic arthritis.

Other lines of therapy

Several other lines of therapy can be used in a trial to improve the host response or to improve the outcome. These therapies include the following:

1. **Antifungal therapy:** Fluconazole (3-6 mg/kg/day, I.V. in 2 divided doses) is indicated when blood culture reveals candida albicans. It may also be used empirically in severe deteriorating cases especially in immunocompromised patients. The available preparation is Diflucan I.V. infusion (100 mg/50 ml).
2. **Intravenous immunoglobulins:** They may be used in fulminant cases in a trial to improve the host response. The dose is 300 mg/kg (10 ml/kg), I.V. infusion, over 6-8 hours, daily for 4-5 days. The available preparation is Sandoglobulin I.V. infusion (1 gm/33 ml) or (3 gm/100 ml).
3. **Corticosteroids:** They are only useful in acute suprarenal failure caused by adrenal hemorrhage (Waterhouse-Friderichsen syndrome) and in meningitis due to hemophilus influenza type b. The empirical use of high doses of steroids in septic shock is no longer recommended as it increases morbidity without reduction in mortality.
4. **Exchange transfusion:** It may be considered in neonates and young infants especially when complications as DIC are also present. Partial exchange in older patients may be considered.
5. **Immunotherapy:** Monoclonal IgM antibodies to endotoxin are recently recommended. Similarly, anti-tumor necrosis factor (anti-TNF) monoclonal antibodies is currently under evaluation. Granulocyte transfusion is indicated in patients who were neutropenic prior to the septic shock.

Parenteral antibacterial drugs used in septicemia

Generic name	Trade name	Dose
Penicillins		
Ampicillin	Ampicillin vial (0.5 gm), (1 gm)	100 mg/kg/day
Sultamicillin	Unasyn vial (375 mg), (750 mg)	100 mg/kg/day
Amoxicillin	Amoxil vial (0.5 gm), (1 gm),	100 mg/kg/day
Co-amoxiclav	Augmentin vial (600 mg), (1.2 gm),	100 mg/kg/day
Piperacillin	Pipril vial (1 gm), (2 gm), (4 gm)	200 mg/kg/day
Cephalosporins		
Cefuroxime	Zinnat vial (750 mg)	100-150 mg/kg/day
Cefotaxime	Claforan vial (0.25 gm), (0.5 gm), (1 gm)	100-150 mg/kg/day
Ceftriaxone	Rocephin vial (0.5 gm), (1 gm)	100-150 mg/kg/day
Ceftazidime	Fortum vial (0,25 gm), (0.5 gm), (1 gm)	100 mg/kg/day
Aminoglycosides		
Gentamicin	Garamycin amp. (20 mg), (40 mg)	6 mg/kg/day
Tobramycin	Nebcin vial (20 mg), (80 mg)	6 mg/kg/day
Netilmycin	Netromycin vial (50 mg), (150 mg)	6 mg/kg/day
Amikacin	Amikin vial (100 mg), (250 mg), (0.5 gm)	15 mg/kg/day
Carbapenems		
Imipenem	Tienem vial. (500 mg in 50 ml solution)	60-100 mg/kg/day
Meropenem	Meronem vial. (500 mg)	60-100 mg/kg/day
Other drugs		
Metronidazole	Flagyl infusion (500 mg/100 ml)	7.5 mg/kg/12 hours
Vancomycin	Vancocin vial (0.5 gm)	40-60 mg/kg/day
Clindamycin	Dalacin C ampoule (300 mg)	20-40 mg/kg/day

PROGNOSIS

The mortality rate of fulminant sepsis and shock is very high (above 50%). Prognosis depends on the causative organism (high mortality with staphylococci, pseudomonas, enterobacter, candida), stage of shock (high with refractory shock) and the number and extent of associated system failures. Mortality can be significantly reduced with proper system support and early aggressive antibiotic therapy.



Section 9

Serious Injuries

- Major Trauma
- Burn Injuries
- Drowning and Near-drowning
- Poisoning

37 Chapter

Major Trauma

Primary survey

Quick examination

- A: Airway cervical spine
- B: Breathing
- C: Circulation
- D: Disability
- E: Exposure

Resuscitation

- A: Airway
- B: Breathing
- C: Circulation
- Other measures

Secondary survey

Head to toe examination

- Head and neck
- Chest examination
- Abdominal examination
- Pelvis and spine
- Extremities

Definitive care

- X-rays
- Special investigations
- Transfer to PICU
- Multisystem support

Serious multisystem trauma is a major cause of death at all ages, and in children, it accounts alone for up to 40-50% of deaths above the age of 1 year. **Traffic road accidents (TRA)** or motor vehicle accidents are the most common cause of serious traumatic injuries. Injuries to passenger occupants are commoner at all ages except in children between 5-9 years where pedestrian injuries predominate. Falls are the second most common cause of serious trauma especially in toddlers and the main cause of injury at home. It is commoner in boys and in low socioeconomic groups. **Intentional trauma (child abuse)** may also be considered in young infants who cannot yet stand or walk.

ADVERSE EFFECTS

Major trauma has physical, physiological and psychological effects

- **Physical injuries** are ranging from minor cutaneous bruises to serious fatal multiple organ system failures. Respiratory failure (due to airway obstruction, pneumothorax, hemothorax), circulatory failure (hypovolemic shock, obstructive shock, neurogenic shock) and central neurologic failure (due to intracranial hemorrhage) are the most common causes of death.
- **Pathophysiological changes** occur due to stimulation of baroreceptors (blood loss, fall in blood pressure), stimulation of chemoreceptors (hypoxia, CO₂ retention, acidosis) and tissue injury (release of bradykinin, histamine, serotonin, prostaglandins and leukotrienes). The main effects of these changes are sympathetic

stimulation (catecholamine release) and hormonal stimulation (release of cortisol, aldosterone, ACTH, TRH, renin-angiotensin). These changes are initially a useful defensive mechanism but with time they have harmful effects.

- **Psychological changes** are mainly related to anxiety, fear and pain.

PRIMARY SURVEY

Primary survey in *emergency department* aims to identify immediate life-threatening conditions and to provide emergency resuscitation. This can be achieved by the following two steps:

Quick examination

The ABCDE approach is suitable for rapid recognition of life-threatening conditions in traumatic injuries. The assessment should be made in one minute.

ABCDE approach

A = Airway

Assess airway patency. Extend the head if airway is compromised.
In head trauma, maintain cervical spine in neutral position.

B = Breathing

Assess respiratory rate, color, work of breathing, alertness.

C = Circulation

Assess heart rate, arterial pulsations, capillary refill, skin temperature

D = Disability (neurological status)

Assess mental status (level of consciousness) and pupillary function.

E = Exposure

Remove clothing and look for trauma, hemorrhage.

For simplicity, the level of consciousness can be graded as (1) alert, (2) responsive to voice, (3) responsive to pain, (4) unresponsive.

Resuscitation

Any life-threatening problem discovered during quick examination should be immediately treated.

1. **Airway and cervical spine:** The airway may be compromised by extrinsic material (blood, vomitus, foreign body) or by the tongue and/or pharyngeal soft tissues falling back to obstruct the airway. This is particularly common in injuries where consciousness is lost and hypotension is common. Airway management includes the following:
 - a. **Airway opening:** Jaw thrust (pulling the jaw forward) is effective to relieve obstruction caused by tongue and pharyngeal soft tissues. Head tilt is contraindicated in head trauma and initial immobilization of the neck in neutral position is indicated until cervical spine injury is clinically and radiologically excluded.
 - b. **Airway clearance:** All foreign materials should be removed by gentle suctioning. Finger swap technique should be avoided in children.

- c. **Oropharyngeal airway:** In unconscious child, oropharyngeal airway is inserted to keep the airway patent. Conscious children usually reject it.
 - d. **Endotracheal intubation:** It may be considered if the above measures are ineffective or when effective ventilation with the bag and tube is required.
 - e. **Prevention of aspiration:** All traumatic patients should be considered as having "full stomach" and being at risk of pulmonary aspiration. Moreover, gastric emptying is delayed due to trauma, pain and fear. Nasogastric tube is inserted and the stomach is evacuated.
2. **Breathing support:** Arterial hypoxemia is very common in traumatic injuries due to several reasons including CNS depression, pneumothorax, flail chest and lung injury (pulmonary contusion, aspiration). Breathing control aims to ensure adequate oxygenation and ventilation. Management includes the following aspects:
- a. **100% oxygen with a face mask** is indicated to ensure adequate oxygenation and to correct hypoxemia.
 - b. **Assisted ventilation** is indicated in presence of apnea or hypoventilation. Bag and mask ventilation is initially tried. Endotracheal intubation and bag and tube ventilation is indicated in presence of pneumothorax, flail chest or shock. Unequal air entry should suggest pneumothorax, blocked tube or blocked main bronchus.
3. **Circulation support:** Shock in traumatic injuries is multifactorial. It can be hypovolemic (due to blood loss), obstructive (due to pneumothorax and/or cardiac tamponade) and neurogenic (due to head injury). Urgent management of hemorrhagic shock includes the following aspects:
- a. **Control of hemorrhage:** Control of obvious external bleeding can be simply made by direct pressure over the site of hemorrhage. Massive abdominal hemorrhage or hemorrhage following fractures of lower limbs can be controlled by with a pressurized pneumatic garment as military antishock trouser device (MAST suit). When control of hemorrhage is difficult, immediate transfer to operation room should be considered after initial stabilization.
 - b. **Preload augmentation:** Immediate I.V. line or intraosseous line should be established and 20 ml/kg of Ringer's lactate or normal saline is infused over 10-15 minutes. When the response is inadequate, the amount can be repeated once or even twice. A colloid (as salt free albumin) may also be given in an amount of 10-20 ml/kg. Failure of response to crystalloid and colloid infusion should suggest continued unrecognized blood loss (internal hemorrhage) and urgent surgical consultation is indicated.
 - c. **Urgent whole blood transfusion:** It is indicated in amount equal to the estimated acute blood volume loss (20 ml/kg, 30 ml/kg or 40 ml/kg). In emergency situation of severe hemorrhage, uncross-matched O-negative blood can be used. Full cross-matched blood usually takes 45-60 minutes to obtain (see acute blood loss).
4. **Other measures:** Proper recording of physical findings and resuscitative measures are necessary. **Strong analgesia** to control pain is important when pain is severe.

Morphine (0.1 mg/kg, I.V.) or fentanyl (1-2 mcg/kg, I.V.) can be used. Available preparation is Fentanyl vial (0.1 mg/2 ml). Urinary catheterization is indicated if the child cannot pass urine spontaneously or if continuous accurate output measurement is required.

Primary survey should take 20-30 minutes and should be immediately followed by the secondary survey.

SECONDARY SURVEY

Secondary survey is only started after initial stabilization of the child. When the primary survey and resuscitation do not stabilize the child, urgent surgical intervention is indicated. It is also important to emphasize that continuous monitoring of vital signs throughout the secondary survey is important and any detected deterioration should lead to an immediate return to primary survey. Secondary survey includes the following aspects:

Head-to-toe examination

Complete physical examination, including the child's back, should be made systematically where all body areas are evaluated. The order of physical examination may vary according to urgency. Although head trauma is the most serious, chest injuries and abdominal injuries are more urgent because they can be rapidly fatal.

1. **Head and neck examination:** Head examination starts with eye examination where conjunctiva, pupillary size and reaction to light are evaluated. Ear and nose are then examined for cerebrospinal fluid (CSF) or blood, which indicates either basal skull fracture or meningeal tear. Face and scalp are examined for bruising, lacerations, localized hematoma, skull depression or fractures. Periorbital hematoma (raccoon eyes) should suggest a basilar skull fracture. The neck should be examined without moving the cervical spine until cervical spine injury is excluded radiologically. The neck is examined for subcutaneous emphysema, hematoma or localized pain. It is important to note that coma does not necessarily mean intracranial hemorrhage and hypoxic or ischemic encephalopathy is a more common cause of altered consciousness.
2. **Chest and heart examination:** Immediate life-threatening chest injuries include tension pneumothorax, open pneumothorax, massive hemothorax, flail chest (rib fractures) and hemopericardium (cardiac tamponade). Chest and heart examination should be first directed to identify these conditions by the characteristic clinical features. Serious injuries that may be discovered later include pulmonary contusion, tracheal or bronchial rupture and disruption of great vessels.
3. **Abdominal examination:** It is important to remember that major intra-abdominal injuries can occur without obvious external signs. Intra-abdominal hemorrhage should be considered in the following situations; (1) shock not responding to fluid resuscitation and without an obvious external blood loss (2) rapidly expanding abdominal circumference (abdominal circumference should be measured every

10-15 minutes), (3) aspirated blood from the nasogastric tube, (4) localized tenderness or rigidity. Back examination is a part of abdominal examination and the child should be turned for back examination.

4. **Pelvis and spine:** Initial inspection for bruising, laceration or deformity is important. The bony prominences of the pelvis are palpated for tenderness or abnormal mobility. The perineum is carefully examined for lacerations, hematoma or bleeding. The external urethral meatus is inspected for blood. Spine examination is made for swelling, bruising, tenderness or deformity.
5. **Extremities:** Initial examination for bruising, hematomas, deformities, crepitus and focal tenderness is important. Neurovascular examination is important for detection of injuries of blood vessels and nerves. With interrupted blood flow to an extremity, the 4 Ps are present (pulselessness, pallor, paresthesia and paralysis). Severe pain with passive movements may indicate fracture and/or compartment syndrome (bleeding and edema inside an intact fascial compartment).

Detailed history of the onset and nature of the injury should be taken from parents, relatives, ambulance personnel and the child himself if he is conscious.

Definitive care

Following complete examination of the secondary survey, the child is either hemodynamically stable or unstable.

- **Hemodynamically unstable child** should be immediately taken to the operating room for surgical exploration. A team of surgeons including general surgery, chest surgery, neurosurgery and orthopedic surgery should be available. One physician should be responsible for the whole child so that the injured child is not lost between different specialties.
- On the other hand, **hemodynamically stable child** should follow the following steps:
 1. **X-rays:** All seriously injured children must have radiographs of the lateral cervical spine, chest, abdomen, pelvis, spine and long bones. Skull X-ray is indicated in infants and in presence of skull depression, skull penetration, CSF from nose or ear, raccoon sign, loss of consciousness for 5 minutes or focal neurologic signs.
 2. **Other diagnostic procedures:** Echocardiography is urgently indicated in suspected cardiac tamponade. CT scan of the head, chest, abdomen or pelvis may also be considered.
 3. **Transfer to pediatric ICU:** The seriously injured child should be then transferred to PICU for monitoring and multisystem support. Appropriate urgent surgical consultation should be considered according to the results of radiographs and other diagnostic procedures. It is important to re-emphasize that chest and abdominal injuries can be rapidly fatal and management of these injuries should always take priority. CT scan of the head, when indicated, should be postponed until chest and abdominal injuries are under control.
 4. **Multisystem support:** Respiratory failure in seriously injured children is multifactorial. Early discovered causes include CNS respiratory depression,

airway obstruction, pneumothorax, hemothorax and flail chest. In the ICU, other causes as pulmonary contusion, aspiration pneumonia, diaphragmatic injury, tracheobronchial tear and adult respiratory distress syndrome may also be responsible. Endotracheal intubation, mechanical ventilation and thoracocentesis are almost necessary. Cardiovascular failure is also common due to hemorrhagic shock, cardiac tamponade, myocardial contusion and rupture of great vessels. Appropriate cardiovascular support is extremely important. Central neurologic failure with coma, convulsions and increased ICP is also common due to hypoxic-ischemic injury, brain lacerations and intracranial hemorrhage. Proper control of convulsions and rapid measures to reduce the increased intracranial pressure are crucial. Metabolic failure especially acute renal failure is also common and it necessitates urgent recognition and immediate treatment.

Summary of management of major trauma

Primary survey (A+B+C+D+E)

To identify patients in need of resuscitation (see emergency approach)

Cardiopulmonary resuscitation

For those with cardiopulmonary arrest or near arrest.

Secondary survey

To identify the failing system or systems

Careful examination (head-to-toe examination):

Head: Look for fractures, CSF from nose or ears (fracture base), fracture spine.

Chest: Look for open pneumothorax, hemothorax, flail chest (rib fractures).

Abdomen: Look for intra-abdominal hemorrhage (very important, see below).

Pelvis and spine: Look for bony prominences, spine deformity.

Extremities: Look for injured vessels, fractures.

Definitive care

(A team of general surgeon, chest surgeon, neurosurgeon, orthopedic surgeon and ICU doctors is essential)

— Hemodynamically unstable patient operating room for surgical exploration.

— Hemodynamically stable patient → follows the following steps:

X-rays: Abdominal and chest X-rays are more urgent than CT scan of the head.

Ultrasound to detect hemopericardium and intra-abdominal hemorrhage.

Transfer to pediatric ICU.

Multisystem support of the failing systems.

Monitoring

Recording clinical, laboratory and therapeutic measures.

38

Chapter

Burn Injuries

Primary survey

Quick examination

- A: Airway
- B: Breathing
- C: Circulation
- D: Disability
- E: Exposure

Resuscitation

- A: Airway control
- B: Breathing support
- C: Circulation support
- Other measures

Secondary survey

Head to-toe examination

- Extent of burn
- Depth of burn
- Burn to special areas
- Cause of burn
- Other injuries

Definitive care

- I.V. fluid therapy
- Albumin or plasma
- Nutrition
- Wound care

Next to traffic road accidents, burns are the most common cause of serious injuries and accidental deaths in adults and children. The incidence in children is much higher in low socioeconomic classes where poor housing conditions, family stress, child neglect and abuse are major contributing factors. Burns are caused by exposure to fire, hot liquids, chemicals or electrical current. Flame burns are the most serious where smoke inhalation, and not the burn, is the main cause of death. Scald burns are the most common (85% of cases) especially in children below the age of 4 years. They are usually caused by hot liquids (as hot tea), hot bath water and hot cooking oil. Serious effects of scald burns are mainly related to the extent and depth of burned area. Chemical and electrical burns are the least common (2-3% of cases). It is important to remember that intentional burns (child abuse) are not uncommon; therefore, assessment of the extent and depth of the burn and its consistency with the history is important.

ADVERSE EFFECTS

The morbidity and mortality of burns depends on several factors:

- **Severity of the burn:** It is related to the temperature and the duration of contact. It is clinically assessed by the extent of the burn (affected surface area), depth (affected skin layers) and involvement of special areas (face, hands, perineum).
- **Pathophysiological changes:** Respiratory and cardiovascular effects are the most common and most serious complications. Smoke inhalation in fire burns is the

main cause of death. Airway obstruction (inhalational injury) is also common in fire burns and is usually caused by airway edema especially during the first 2-3 days (edema phase). Hypovolemic shock occurs in extensive burns due to plasma loss from circulation into the extravascular spaces.

- **Associated injuries:** In fire burns, associated traumatic injuries are common and they usually occur due to falling objects or running and jumping in trials to escape fire.

PRIMARY SURVEY

Primary survey in *emergency department* aims to identify immediate life-threatening conditions and to provide emergency resuscitation. It includes the following two steps:

Quick examination

The ABCDE approach (previously mentioned in major trauma) is also suitable for rapid recognition of acute life-threatening conditions in burn injuries. Assessment of the airway, breathing, circulation, disability and exposure (removal of wet or burned clothes) should be made in one minute (see major trauma).

Resuscitation

Any life-threatening problem discovered during quick examination should be immediately treated.

1. **Airway and cervical spine:** In fire burns and exposure to smoke, airway obstruction due to inhalational injury is a common problem. The condition should also be considered in presence of face burns or smoke deposits around the mouth and nose. As the airway may deteriorate rapidly, inhalational injury should be managed by endotracheal intubation because the procedure will be much difficult with progression of edema. If there is any suspicion of traumatic injuries, cervical spine immobilization is important until cervical spine injury is radiologically excluded.
2. **Breathing:** 100% oxygen is initially given to all burned children especially those with suspected inhalational injury. Mechanical restriction of chest movements and breathing difficulty may occur in circumferential burns to chest wall. Ventilatory support should be considered if hypoventilation occurs.
3. **Circulation:** Hypovolemic shock due to plasma loss is unusual during the first few hours following burns, and if hypovolemic shock is present, associated blood loss should be considered. An immediate I.V. line should be established and should be away from the burned areas. Intraosseous route may be considered in extensive burns. Ringers lactate (20 ml/kg, I.V.) should be started if hypovolemic shock is present.
4. **Other measures:** Proper recording of physical findings and resuscitative measures are important. Strong analgesia is essential to control pain, which is usually severe. Morphine (100 microgm/kg, I.V.) or fentanyl (1-2 microgm/kg, I.V.) can be used and repeated every 3-4 hours (with morphine) or 0.5 - 1.0 hour (with fentanyl).

Cooling of the burn with cool water is effective to decrease pain, to lower the temperature of the injured tissue and to prevent further damage to skin. Urinary catheterization is indicated if the child cannot pass urine spontaneously or if the genitalia are affected.

SECONDARY SURVEY

Secondary survey starts after stabilization of the burned child. The cause and the time the burn occurred should be noted and recorded.

Head-to-toe examination

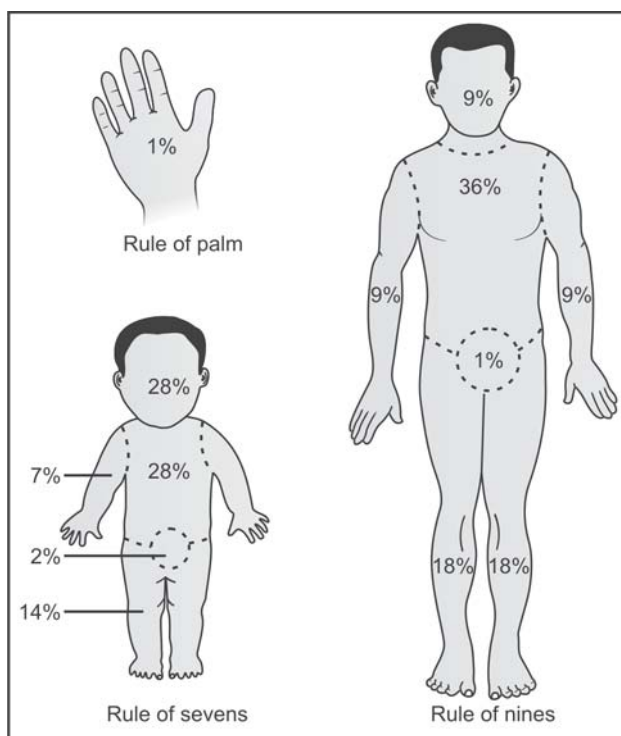
Complete physical examination aims to assess the severity of the burn (extent, depth, special areas) and to discover associated injuries, which are common with fire burns.

1. **Extent of the burn:** It is estimated by the percentage of the affected body surface area. Hypovolemic shock is likely to occur if more than 10% of the body surface area is affected. Calculation of the affected surface area is made by different methods:
 - a. *The rule of palm:* It is an easy way, which can be used when accurate charts are not available. The palm of the burned child (from wrist crease to fingers crease) covers an area of approximately 1% of the total body surface area. Another advantage of this simple rule is its relation to the child's size.
 - b. *The rule of sevens:* This rule can be used in infants and young children and it depends on the fact that the surface area of each upper limb is 7%, each lower limb is 14%, front of the trunk is 14%, back of the trunk is 14%, head is 28% and perineum is 2% (total score is 100%).
 - c. *The rule of nines:* It can be only applied above the age of 14 years and it depends on the fact that the surface area of each upper limb is 9%, each lower limb is 18%, front of the trunk is 18%, back of the trunk is 18%, head is 9% and perineum is 1% (total score is 100%).
 - d. *Burn charts:* Accurate burn charts of different ages (infants, young children, and old children) are also available and can be used.
2. **Depth of the burn:** Burns are classified into three degrees according to the involved layers of the skin and they differ in appearance, associated pain and prognosis for healing.
 - a. *Superficial burns:* Only the epidermis is affected. Pain is present and the skin appears red with no or minimal blister formation. Healing usually occurs in three weeks.
 - b. *Partial-thickness burns:* The epidermis is affected with some damage to the dermis. Pain is present and the skin appears red or mottled, and blister formations are usually present. Healing occurs in 6 weeks.
 - c. *Full-thickness burns:* Both epidermis and dermis are injured and deeper structures may also be affected. Pain is absent (painless) and the lesion looks white or brown and is leathery to touch. It does not heal except from edges and skin grafting is almost necessary.
3. **Burn to special areas:** Burns to face are serious and may be associated with inhalational injury. In addition, subsequent scarring may cause significant disfigurement and necessitates plastic surgery. Burns involving the hand may cause scarring and severe functional loss. Burns to perineum are susceptible to infections and

are difficult to manage. If any of these areas are affected, hospitalization is indicated.

4. **Associated injuries:** Traumatic injuries should be excluded especially in fire burns. Detailed history of the cause of burn is usually helpful.

Extent of the burn (Percent of surface area)



Definitive care

Following the complete examination, a clinical decision should be made regarding the place and lines of management.

Home treatment is indicated for minor burns with a less than 10% affected surface area. Cleaning and dressing of the burned area is made with occlusive dressings thick enough to prevent exudates from soaking through. Blisters should be left intact and re-examination can be made after 2-3 days. Oral analgesics are also required to control pain.

Hospital treatment is indicated in burns of more than 10 % body surface area, full-thickness burns more than 5%, burns to special areas (face, hand, perineum) and inhalational injury. Admission is preferably made in a burn unit. Hospital management includes the following aspects:

1. **I.V. fluid therapy:** Children with burns of 10% or more require I.V. fluid therapy for a period of 48 hours after the injury (the shock phase). Two I.V. lines are necessary

one for the maintenance daily requirements and the other for additional requirements to treat the burn. **Parkland formula** can be used to calculate the additional fluid requirements ($4 \text{ ml/kg} \times \text{percentage burn}$). Ringer's lactate is the most commonly used I.V. fluid for additional requirements. One half of the calculated amount is given over the first 8 hours since the time of onset of burn and the remainder half is given over the next 16 hours. During the next 24 hours, only one half of the first day additional requirement is needed and it can be given as a mixture of Ringer's lactate and glucose 5%.

2. **Albumin 5% or plasma transfusion:** It is indicated in children with burns of 20% or more to keep serum albumin level above 2 gm/dl. The required amount can be calculated by **Muir and Barclay formula** ($0.5 \text{ ml/kg} \times \text{percentage burn}$) and it is usually given over 4-8 hours. Whole blood transfusion may also be considered when significant blood loss occurs.
3. **Nutrition:** From the third day, oral feeding can gradually replace the I.V. fluid therapy. Oral fluids, diluted formulas and semisolid foods are tried first and if tolerated, ordinary food can be given and I.V. fluid therapy is discontinued.
4. **Wound care:** Infections are a major risk in burned area and wound care should start as early as possible to reduce this risk. Wound care can be divided into conservative and surgical. Conservative treatment is mostly made by daily application of silver sulphadiazine cream, which keeps the burn moist and prevents infection with pseudomonas. Thick occlusive sterile dressings are used to cover the burned areas. Superficial hand burns can be treated in a plastic bag filled with silver sulphadiazine, and superficial facial burns may be left exposed. Surgical treatment involves the removal of dead tissues and its replacement with skin grafts.

39 Chapter

Drowning and Near-drowning

Primary survey

Quick examination

- A: Airway
- B: Breathing
- C: Circulation
- D: Disability
- E: Exposure

Resuscitation

- A: Airway control
- B: Breathing support
- C: Circulation support
- Other measures

Secondary survey

Head-to-toe examination

- Respiratory
- Cardiovascular
- Neurologic
- Metabolic
- Other injuries

Definitive care

- Respiratory support
- Cardiovascular support
- Neurologic support
- Other system support

Drowning is the third most common cause of accidental death in children. The incidence is much higher in males and in low socioeconomic classes where lack of adult supervision is a major contributing factor. Most deaths occur in children below the age of 5 years.

The term **drowning** means death within 24 hours of submersion while **near-drowning** indicates a submersion injury with survival for more than 24 hours whether the eventual outcome is death or recovery. However, such classification is artificial and has no clinical or therapeutic significance. Near-drowning (submersion injury) is the term used for children requiring therapy for more than 24 hours. Submersion injury may occur in fresh water (rivers, lakes, ponds, swimming pools) or salt water (sea water). The incidence is much higher in summer season, and a disastrous drowning and near-drowning occasionally occur in river cruises.

ADVERSE EFFECTS

When a child is submersed under water, breath-holding and bradycardia occur due to the diving reflex. Within 20 seconds to 2 minutes later, breathing occurs and the inhaled fluid on touching the larynx causes immediate laryngeal spasm. Copious amount of water are then swallowed until the secondary apnea gives way to involuntary breathing, which leads to aspiration of water into the lungs. Anoxia results in loss of consciousness, bradycardia, arrhythmias, cardiac arrest, terminal apnea and death.

When this chain of events is interrupted and the child is lifted out of water, the pathophysiological changes that occur depend on the duration of anoxia, amount of swallowed water, amount of aspirated water and the degree of hypothermia. The main pathophysiological changes (submersion injury) are the following four events:

- **Anoxic-ischemic injury:** Anoxia and ischemia have several adverse effects on most body systems. Anoxic-ischemic encephalopathy (with cytotoxic brain edema and increased ICP), myocardial ischemia (with arrhythmias), adult respiratory distress syndrome (ARDS), renal tubular necrosis and DIC are the most common effects.
- **Pulmonary injury:** Aspiration of water occurs in 80-90% of cases. Although some differences are present between the effects of salt water and fresh water aspiration, there is no significant clinical or therapeutic differences.
- **Hypothermia:** Temperature below 35°C is common with submersion especially in cold water, and it usually becomes worse when resuscitative measures are made with no consideration to rewarming. Hypothermia has several serious effects and resuscitation is usually unsuccessful if body temperature is below 32°C. With moderate to severe hypothermia, multiple organ system failure occurs (respiratory, cardiovascular, neurologic, metabolic and hematologic).
- **Water and electrolyte imbalance:** During submersion, copious amount of water are usually swallowed and absorbed leading to fluid overload. Electrolyte changes depend on the type of water where hyponatremia (with fresh water) or hypernatremia (with salt water) usually occur. Both can lead to brain edema and increased ICP.

Multiple organ system failure (MOSF) in near-drowning (submersion injury)

Respiratory failure

Pulmonary aspiration and aspiration pneumonia (early).
Adult respiratory distress syndrome (late).

Cardiovascular failure

Myocardial ischemia (congestive heart failure, cardiogenic shock, arrhythmias).
Hypervolemia and preload failure.

Central neurologic failure

Anoxic-ischemic encephalopathy (coma, convulsions, increased ICP).
Hyponatremia or hypernatremia (coma, convulsions, increased ICP).

Metabolic failure

Fluid overload and electrolyte disturbance (hyponatremia or hypernatremia).
Renal tubular necrosis (acute renal failure).

Hemostatic failure

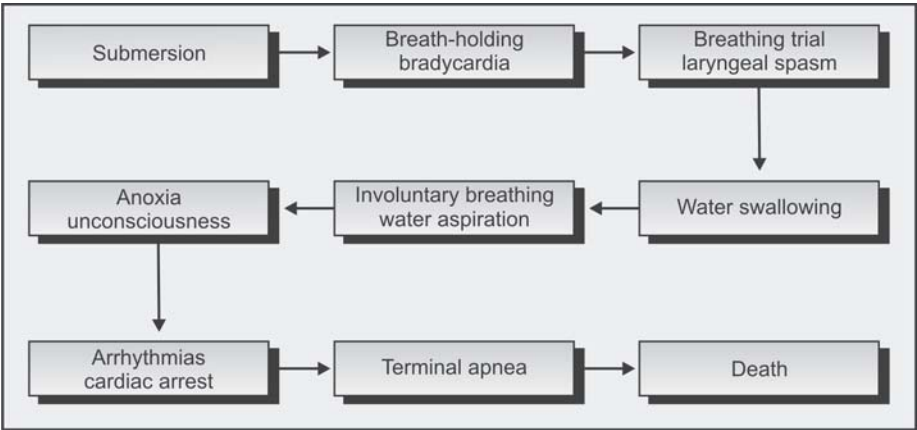
Disseminated intravascular coagulation (DIC).

PRIMARY SURVEY

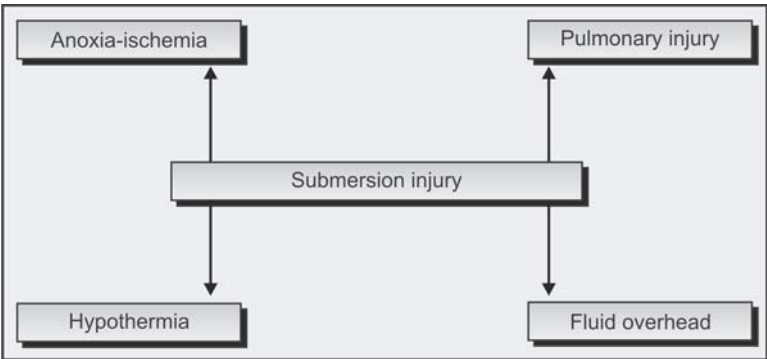
The clinical spectrum of children with submersion injury is wide. Some children with brief submersion arrive at the hospital awake and alert while others, on the other extreme, arrive apneic and arrested and require full cardiopulmonary resuscitation.

Primary survey aims to identify immediate life-threatening conditions and to provide emergency resuscitation. This can be achieved by the following two steps:

Drowning (Submersion death)



Near-drowning (Submersion injury)



Quick examination

The ABCDE approach (previously mentioned in major trauma) is also suitable for rapid recognition of acute life-threatening conditions in submersion injury. Assessment of the airway, breathing, circulation, disability (level of consciousness, pupillary reaction) and exposure (removal of wet clothes) should be made in one minute.

Resuscitation

Any life-threatening problem discovered during quick examination should be immediately treated. Ideally, such resuscitation should be made out-of-hospital at the scene of accident.

1. **Airway and cervical spine:** The airway should be cleared from foreign materials or vomitus. If the child is unconscious, maneuvers to open the airway (jaw thrust) without head tilt should be made until cervical spine injury is excluded. Cervical injury is common especially in water-sport accidents and occasionally trauma is the preceding event of drowning.
2. **Breathing support:** Oxygen therapy is important in children with cyanosis or respiratory difficulty. In children with apnea, persistent cyanosis or hypoventilation assisted ventilation should be immediately started. Mouth-to-mouth ventilation or mouth arid mask ventilation should be quickly followed by endotracheal intubation and hag and tube ventilation especially if altered consciousness and/or cardiac dysfunction are also present.
3. **Circulation support:** Cardiac arrest or severe bradycardia necessitates immediate cardiac compression. Cardiovascular support is often necessary as shock (cardiogenic) and cardiac arrhythmias (myocardial ischemia, hypothermia) are commonly present in severely affected children. Warmed Ringers lactate or normal saline should be given I.V. to support circulation. It is important to remember that hypothermia can give a false appearance of death, therefore, resuscitative measures should continue till core temperature is above 32°C. In addition, arrhythmias are resistant to therapy in presence of hypothermia.
4. **Other measures:** Immediate *treatment of hypothermia* with rewarming is extremely important. External rewarming is enough when core temperature is above 32°C (remove wet clothes, wrap in warm blankets, use overhead radiant warmer and/or infrared heating temperature). With core temperature below 32°C, internal or core rewarming is indicated (warm I.V. fluids, warm humidified oxygen, gastric irrigation with warmed saline, bladder irrigation with warmed saline). Other more invasive rewarming procedures as peritoneal irrigation or pericardial irrigation may also be considered (see metabolic emergencies). Nasogastric tube and stomach evacuation is very important to avoid vomiting and aspiration, and to prevent absorption of ingested water to avoid fluid overload.

SECONDARY SURVEY

Secondary survey starts after initial stabilization of the child. It includes the following aspects:

Head-to-toe examination

Complete physical examination with particular emphasis on respiratory, cardiovascular, neurologic and metabolic functions is essential. Associated injuries especially traumatic spinal injuries should be considered and excluded.

Children with submersion accidents and without apparent injury, should be observed for 6-12 hours in emergency department because respiratory difficulty may appear several hours after the event due to aspiration of water or evolving adult respiratory distress syndrome.

Definitive care

Children who required resuscitative measures, those with disturbed consciousness and those with respiratory manifestations should be admitted to a pediatric intensive care unit where monitoring (clinical, laboratory, radiological) multisystem supports are necessary.

1. **Respiratory support:** Children with submersion injury can be initially divided into wet and dry according to the presence or absence of significant aspiration. Aspiration occurs in up to 90% of cases and it occurs during submersion or during resuscitation. Even children who are initially dry may develop adult respiratory distress syndrome (secondary drowning phenomenon). Endotracheal intubation and mechanical ventilation are indicated in those with respiratory failure, circulatory failure or altered consciousness. Hyperventilation is necessary in those with brain edema and markedly increased intracranial pressure (see below).
2. **Cardiovascular support:** Although cardiovascular dysfunctions are relatively uncommon in near-drowning children, congestive heart failure, cardiogenic shock and cardiac arrhythmias do occur. Proper and vigorous support of any discovered dysfunction is important. It is also important to remember that hypervolemia secondary to ingested water and resuscitation fluid may lead to preload heart failure.
3. **Neurologic support:** Neurologic injury in near-drowning is the most important determining factor in the eventual mortality and morbidity. Very high mortality and/or severe neurologic sequelae should be expected in children with deep coma, severe acidosis and in those requiring cardiopulmonary resuscitation in the emergency department. Neurologic support starts with early and vigorous support of the airway, breathing and circulation. Control of convulsions and reduction of the increased intracranial pressure are of equal importance. Metabolic causes of brain edema as hyponatremia or hypernatremia should also be corrected. (see coma, increased intracranial pressure and metabolic emergencies).
4. **Other system support:** Metabolic disturbances as hypothermia, hyper-volemia and electrolyte disorders (hyponatremia or hypernatremia) should be corrected. Hemostatic failure due to DIC should also be corrected.

OUTCOME

Children who are awake at initial examination or who regain full consciousness within 24 hours have an excellent prognosis of recovery without sequelae. On the other hand, children who require cardiopulmonary resuscitation or who are deeply comatose have a high mortality rate or high incidence of severe neurologic sequelae including persistent vegetative state (see neocortical death).

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Chapter

Poisoning

Primary survey

Quick examination

- A: Airway
- B: Breathing
- C: Circulation
- D: Disability
- E: Exposure

Resuscitation

- A: Airway
- B: Breathing
- C: Circulation
- Other measures

Secondary survey

History and examination

- Detailed history
- Complete examination
- Repeated re-evaluation

Definitive care

- Multisystem support
- Measures to the poison
 - Antidotal therapy
 - Preventing absorption
 - Enhancing excretion

Poisoning in children is a common clinical problem and common cause of hospital admission for observation and treatment. Poisoning can occur with drugs, cleaning agents, insecticides, paints, petroleum products, plants and inhalation of toxic gases as carbon monoxide or other toxic gases or fumes. **Accidental poisoning** is the most common cause and it usually occurs in children below the age of 5 years, the age at which children usually put things in their mouths. Family stresses and lack of supervision are important contributing factors. **Intentional poisoning** (child abuse) should also be considered especially in children below the age of 5 years. Suicide attempts may also be considered in adolescents. **Iatrogenic poisoning** due to drug overdosage is also common. Digoxin, theophylline and anticonvulsants are the most commonly encountered drugs in iatrogenic poisoning. **Drug abuse** in adolescents as alcohol, psychostimulants, antidepressants and hallucinogens should also be considered.

ADVERSE EFFECTS

Due to the multiplicity of drugs and other several agents that can cause poisoning, the pathophysiological changes can almost affect every system. The clinical manifestations and the severity of findings depend on the causative agent, amount taken and the time interval between the exposure to poisoning and the onset of medical intervention.

Respiratory, cardiovascular and neurologic manifestations are the most common, most serious and the main causes of death in fatal cases. Gastrointestinal and cutaneous manifestations are also common presentations.

It is very important to emphasize that identification of the poison is not the most critical aspect in diagnosis and management and precious time should not be lost on trying to identify the causative poison. **Good supportive care** is the backbone of any successful therapy of poisoned children.

Common clinical presentations of poisoning

Clinical presentation	Causative poison
Respiratory	
Tachypnea	Salicylates, carbon monoxide
Wheezing, secretions	Organic phosphorus poisoning
Hypoventilation	Sedatives, anticonvulsants, alcohol
Cardiovascular	
Hypotension	Sedatives, anticonvulsants, beta-blockers, iron
Hypertension	Sympathomimetics (especially nasal decongestants)
Arrhythmias	Digoxin, theophylline, tricyclic antidepressants.
Neurologic	
Convulsions	Theophylline, antihistamines, tricyclic antidepressants
Ataxia	Phenytoin, antihistamines, salbutamol, alcohol.
Dystonia	Chlorpromazine, metoclopramide
Drowsiness, Coma	Sedatives, hypnotics, anticonvulsants, opiates, antihistamines, tricyclic antidepressants, alcohol, organic phosphorus poisoning, salicylates.
Constricted pupils	Organic phosphorus, opiates, anticonvulsants
Dilated pupils	Atropine, tricyclic antidepressants
Digestive	
Vomiting, diarrhea	Iron, organic phosphorus
Hematemesis	Iron, salicylates
Mucocutaneous	
Cyanosis	Methemoglobinemia (nitrates, nitrites)
Red flushing	Anticholinergics (as atropine), carbon monoxide
Dry skin	Anticholinergics
Sweating	Barbiturates, organic phosphorus
Purpura	Salicylates
Jaundice	Paracetamol, iron
Lacrimation, salivation	Organic phosphorus
Oral lesions	Corrosives
Abnormal odor	Acetone (alcohol, salicylates)
	Alcohol (Ethanol, methanol alcohol)
	Garlic (organic phosphorus, arsenic)
	Petroleum (petroleum products).

- The most commonly involved drugs in severe poisoning are sedatives, anticonvulsants, antihistamines, tricyclic antidepressants, opiates, theophylline, digoxin, beta-blockers, aspirin, paracetamol, iron, organic phosphorus, petroleum products and alcohol.

- **Identification of the causative poison** can be made by the history, clinical manifestations and analysis of samples (from the containers, gastric lavage, urine and blood). Consultation of a poison center is important.

BASIC CONSIDERATION

In some cases, the diagnosis of poisoning is clear and obvious when a frank history of drug intake or ingestion of a toxic substance is obtained. In other cases, the diagnosis is difficult or not even considered. Therefore, the possibility of poisoning should be considered in any child, especially below 5 years, who acutely develop respiratory distress, shock, cardiac arrhythmias, abnormal behavior, abnormal movements (ataxia, dystonia), convulsions, disturbed consciousness, severe digestive manifestations or cutaneous manifestations.

PRIMARY SURVEY

Primary survey aims to identify immediate life-threatening conditions and to provide emergency resuscitation. This can be achieved by the following two steps:

Quick examination

The ABCDE approach (previously mentioned in major trauma) is also suitable for rapid recognition of acute life-threatening conditions in poisoning. Assessment of airway, breathing, circulation, disability (convulsions, level of consciousness, pupillary size and reaction) should be made in one minute. Rapid examination of the oral cavity (foreign body, drug particles, ulcerations, abnormal odor) is also important.

Resuscitation

The most serious life-threatening conditions in poisoned children are airway obstruction, respiratory distress or depression, shock, cardiac arrhythmias and convulsions. Any of these conditions, if detected, should be immediately dealt with.

1. **Airway control:** The airway should be cleared from foreign materials (drug particles, vomitus). If the child is unconscious, maneuvers to open the airway (head tilt, jaw thrust) should be made.
2. **Breathing support:** 100% oxygen is given to those with inhalational injury, cyanosis or respiratory distress. If the child is hypoventilated, assisted ventilation should be started immediately. Mouth-to-mouth ventilation or bag and mask ventilation should be immediately followed by endotracheal intubation and bag and tube ventilation especially if deep coma or cardiac dysfunction are also present.
3. **Circulation support:** An I.V. line should be immediately inserted. Hypotension, if present, usually responds dramatically to shock therapy 'with Ringer's lactate (20 ml/kg, I.V. over 10-15 minutes). ECG monitoring for detection of cardiac arrhythmias is important. Serious arrhythmias as severe bradycardia or ventricular tachycardia should be immediately corrected. Stable arrhythmias (not causing congestive heart failure or shock) can be clinically monitored by the continuous ECG display.

4. **Control of convulsions:** If convulsions are present, immediate control by I.V. diazepam (0.5 mg/kg, slow I.V.) should be made.
5. **Other measures:** *Nasogastric tube* and gastric lavage is indicated in unconscious intubated patient and in those who ingested large doses of aspirin or iron tablets. Gastric lavage is mainly useful if it is done within 4 hours of ingestion of toxic substance. However, with aspirin, opiates and tricyclic antidepressants, gastric lavage can be made within 12 hours of ingestion. A sample of gastric content should be sent for analysis. Specific antidote may also be considered if the drug is known and specific antidote is available (see below).

SECONDARY SURVEY

Secondary survey starts after the initial stabilization of the patient and it includes the detailed clinical evaluation and the definitive care.

History and examination

Detailed history should be obtained from the parents, family members or friends who have accompanied the child to the hospital. History should include the trade name of the given drug and the time since exposure. The container of any ingested drug and remaining contents should be brought. Information regarding the amount taken should be obtained and it is wise to assume the worst. For instance, if 7 tablets of the medicine are missing, we should assume that the child has taken them all.

Complete examination of all systems should be made carefully and should be repeated at regular short intervals as new symptoms and signs may appear during the period of observation.

Symptomatic children should be hospitalized for observation and further management. Children with serious life-threatening manifestations as respiratory depression, cardiac arrhythmias, coma or convulsions should be admitted in a pediatric intensive care unit.

Definitive care

Definitive care of poisoned children has two main objectives. First, is to provide supportive care of the potential or actual failing systems (respiratory, cardiovascular, neurologic, metabolic). Second, is the measures directed to the poison itself (to counteract its effect, to prevent absorption and to enhance excretion).

1. **Multisystem support:** It is important to re-emphasize that good supportive care is the most important aspect in management of poisoning. *Deaths from poisoning* mostly occur due to lack of good supportive care and not lack of specific antidote.
 - a. **Respiratory support:** Oxygen should be given to patients with respiratory distress. Monitoring of oxygenation by measurement of arterial oxygen saturation (by pulse oximeter) and arterial blood gases is important. Positive pressure support is indicated in patients with persistent hypoxemia and/or hypoventilation.

- b. **Cardiovascular support:** Treatment of shock and/or cardiac arrhythmias is extremely important. Repeated clinical evaluation of cardiovascular condition and continuous display of ECG are important.
 - c. **Neurologic support:** Following the basic ABC, control of convulsions, if present, and prevention of further fits are important. Repeated assessment of the level of consciousness, pupillary size and reaction to light is important.
 - d. **Metabolic support:** Correction of temperature abnormalities, acid-base disorders, electrolyte disorders and blood sugar disorders are extremely important. Repeated measurement of body temperature, blood gases, serum electrolytes and blood sugar are important. Metabolic acidosis, hypoglycemia and hyperglycemia are common.
 - e. **Hematologic support:** In carbon monoxide poisoning due to inhalational injury, 100% oxygen should be given as early as possible to reduce the concentration of carbon monoxide and to increase oxygen transport to tissues. Diagnosis is considered in patients with low arterial oxygen saturation in spite of normal or even increased PaO_2 . Because of absent cyanosis and normal pink appearance in carbon monoxide poisoning, the condition can be overlooked if arterial oxygen saturation is not measured. Hyperbaric oxygen therapy is currently considered the treatment of choice of carbon monoxide poisoning whether with or without smoke inhalation. The hyperbaric oxygen has the advantage of increased ability to compete with carbon monoxide for hemoglobin binding sites. Cyanosis not responding to 100% oxygen should suggest methemoglobinemia due to nitrites or nitrates poisoning. Diagnosis is confirmed by the presence of low arterial oxygen saturation in spite of normal or even increased PaO_2 . A drop of the patient's blood on exposure to air will remain blue. Methylene blue at a dose of 0.1-0.2 ml/kg (1-2 mg/kg) in a 1% solution is therapeutic (see antidotal therapy).
2. **Measures directed to the poison:** Administration of specific antidote (if available), prevention of absorption and enhancement of excretion are the three standard measures used to minimize the effects of the poison.
- a. **Antidotal therapy:** Unfortunately, only few drugs and poisons of which a specific antidote is available. Carbon monoxide, cyanide, organic phosphorus, methemoglobinemia, opiates, chlorpromazine and iron poisoning are the main indications of immediate antidotal therapy.
 - b. **Preventing absorption:** Measures to decrease absorption of ingested poison include emesis, gastric lavage and administration of activated charcoal and cathartics.
 - i. **Emesis:** Induction of vomiting by administration of syrup of: ipecac (14-30 ml) followed by water may be used in children. However, the risk of aspiration should be considered. Emesis is not recommended in infants.
 - ii. **Gastric lavage:** Insertion of nasogastric tube and gastric lavage is mainly indicated in unconscious intubated patients or in those who ingested large doses of aspirin or iron tablets. It is mainly effective if it is done within 4 hours of ingestion. However, with aspirin, opiates and tricyclic anti-depressants, gastric lavage can be made within 12 hours of ingestion.

Antidotal therapy of some specific poisoning

Poison	Antidote	Dosage
Carbon monoxide	Oxygen	100% or hyperbaric oxygen
Methemoglobinemia	Methylene blue	1-2 mg/kg, I.V. over 10 minutes
Organic phosphorus	Atropine	0.1 mg/kg, I.V. every 10-30 minutes until pupillary dilatation occurs.
Opiates, narcotics	Naloxone	0.1 mg/kg, I.V. may be repeated twice.
Iron	Deferoxamine	10-15 mg/kg/hour (I.V. infusion)
Chlorpromazine	Diphenhydramine	0.5-1.0 mg/kg, I.V. or I.M.
Isoniazid	Pyridoxine (B ₆)	5 gm I.V.
Lead	EDTA	250 mg/m ² /dose, I.M. every 4 hours
Cyanide	Na nitrite, Na thiosulphate	Depends on hemoglobin level

- iii. *Activated charcoal*: After emesis or gastric lavage, activated charcoal (1 gm/kg, mixed with water) should be given to almost all cases. It is capable of adsorbing almost all drugs, thereby decreasing their absorption from the gastrointestinal tract. The dose may be repeated every 2-4 hours until the first charcoal stool appears.
 - iv. *Cathartics*: Administration of cathartics to hasten emptying of gastrointestinal tract may be used in older children. They shorten the intestinal transit time by their osmotic load. Sodium or magnesium sulphate (250 mg/kg, as 10-20% solution) can be given and repeated every 2-4 hours until the passage of a charcoal-stained stool.
- c. *Enhancing excretion*: Measures to enhance excretion include forced diuresis, hemodialysis, hemoperfusion, activated charcoal and exchange transfusion.
- i. *Forced diuresis*: It is a useful technique in drugs mainly excreted by the kidney and it is usually combined by alkalinization of urine. 2 to 5 times the maintenance I.V. fluids are given to establish a urine output of 2-5 ml/kg/hour. Sodium bicarbonate is added to the solution in a concentration of 50-75 mEq/litre. Concomitant use of diuretics as furosemide and mannitol is indicated to ensure high urine flow rate.
 - ii. *Hemodialysis or hemoperfusion*: These techniques are mainly indicated in severe poisoning with salicylates, theophylline or methanol.
 - iii. *Activated charcoal (gastrointestinal dialysis)*: Activated charcoal (1 gm/kg, every 2-4 hours) is also useful to increase nonrenal clearance of drugs as phenobarbital, theophylline, digoxin and carbamazepine. It is also effective even if these drugs are given parenterally.
 - iv. *Exchange transfusion*: It may be considered in newborns and young infants especially when hemolysis or methemoglobinemia is present.



Section 10

Neonatal Emergencies

- Neonatal Respiratory Distress
- Neonatal Convulsions
- Neonatal Sepsis or Septicemia
- Early-onset Neonatal Jaundice
- Serious Neonatal Vomiting

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Chapter

Neonatal Respiratory Distress

Diagnosis

Degree of distress

- Grade I (mild distress)
- Grade II (moderate distress)
- Grade III (severe distress)
- Grade IV (advanced distress)

Cause of distress

- Pulmonary causes
- Extrapulmonary causes

Management

Respiratory monitoring

- Clinical monitoring
- Oxygen saturation
- Arterial blood gases

Respiratory support

- Oxygen therapy
- Positive pressure support

Specific treatment

Respiratory distress is the most common neonatal emergency and the main cause of admission to neonatal intensive care units. Hyaline membrane disease is by far the most common cause (more than 50% of cases) followed by neonatal pneumonia, transient tachypnea and meconium aspiration.

DIAGNOSIS

Degree of distress

Clinical assessment of the degree of distress is important for determination of the severity and course of illness and for choice of the appropriate line of respiratory support.

Grades of respiratory distress

- Grade I** (mild distress): Rapid respiration (above 60/minute) and working alae nasi.
- Grade II** (moderate distress): Intercostal and subcostal retractions.
- Grade III** (severe distress): Expiratory grunting.
- Grade IV** (advanced distress): Central cyanosis and disturbed consciousness.

Cause of distress

In spite of the long list of conditions presenting with respiratory distress, it is usually not difficult to distinguish between the different causes based upon the history, clinical examination and simple investigations. Clinical evaluation should include the mode of delivery (vaginal or C.S.), birth weight, gestational age, color (pallor, plethora or

cyanosis) and systemic examination (CNS, chest, heart and abdomen). Initial clinical exclusion of congestive heart failure is important. Chest examination should begin with comparison of the air entry on both sides to detect conditions with unequal air entry as pneumothorax and diaphragmatic hernia.

Pulmonary Causes

- 1. Hyaline membrane disease:** It is by far the most common cause. It occurs principally in *premature babies* due to deficient synthesis of surfactant by type II alveolar cells which results in massive alveolar atelectasis. Other factors as cold injury, anoxia, acidosis and hypovolemia further impair surfactant synthesis. Manifestations of respiratory distress appear at birth or few hours later and increase gradually to reach its peak in the second or third day. Auscultation of the chest reveals bilateral fine consonating crepitations and air entry may be markedly diminished especially in severe cases. Chest X-ray reveals a fine granular appearance (ground glass appearance) in mild to moderate cases and complete opacification of both lung fields (white lungs) in severe cases. Natural gradual improvement occurs in survivors after the third day over 3 - 5 days. Complications as respiratory failure, apnea, intraventricular hemorrhage and paralytic ileus are common. Mechanical ventilation, which is frequently used, may be complicated with pneumothorax, interstitial emphysema and bronchopulmonary dysplasia and the course may be prolonged for a few weeks.
- 2. Transient tachypnea of the newborn:** It mainly occurs in *full term babies* born by Cesarean section due to delayed clearing of lung fluids. Respiratory distress appears within few hours after birth and is usually mild (just tachypnea). Rapid improvement usually occurs over 24 hours but tachypnea may remain for 2 - 3 days. Chest X-ray reveals coarse streaking and fluid in the fissures (wet lung appearance).
- 3. Meconium aspiration syndrome:** It mainly occurs in *full term and post-term babies* subjected to fetal distress with passage of meconium into the amniotic fluid. Aspiration of meconium-stained amniotic fluid usually occurs at birth and results in respiratory distress within few hours after birth. The skin and umbilical cord may be stained with meconium. Pneumothorax and pneumonia are common complications of severe cases. Chest X-ray reveals hyperinflated lungs with bilateral patchy consolidation. Similar disorders may be caused by aspiration of normal amniotic fluid or milk and result in aspiration pneumonia. Predisposing conditions as tracheoesophageal fistula and gastroesophageal reflux should be considered and excluded.
- 4. Neonatal pneumonia:** Pneumonia in the newborn can be congenital or acquired. *Congenital pneumonia* is characterized by early onset of respiratory distress within 3 - 6 hours after birth (early onset pneumonia). The clinical and radiological findings may be very similar to those of hyaline membrane disease or aspiration pneumonia. Helpful differentiating features include temperature instability, apneic spells and acidosis. Skin rash or hepatosplenomegaly may also be present.

In acquired pneumonia, the onset of respiratory distress is usually after the first 24 hours or at any time in neonatal period (late onset pneumonia). It commonly follows aspiration, mechanical ventilation or septicemia. The pneumonia may be a bronchopneumonia or lobar pneumonia with massive unilateral consolidation. In case of bronchopneumonia, bilateral fine consonating crepitations are the main finding. With massive consolidation, unilateral dullness and diminished air entry over the involved side are evident. Simple sepsis screen (CBC, ESR, CRP) is useful in suggesting an infection. Definite diagnosis depends on isolation of the organism by blood culture and culture of tracheal aspirate.

5. **Persistent fetal circulation (PFC):** Persistent pulmonary hypertension causes right-to-left shunting through the Foramen ovale and ductus arteriosus, which results in severe hypoxemia. It may occur as an idiopathic disorder or secondary to other critical illness as hyaline membrane disease, meconium aspiration, neonatal pneumonia, diaphragmatic hernia or polycythemia. Central cyanosis unresponsive to oxygen therapy is the main clinical finding in idiopathic cases and the condition can be easily confused with congenital cyanotic heart disease. Respiratory distress is variable, chest auscultation is unrevealing and cyanosis characteristically becomes more intense with crying. In secondary cases, the manifestations of the primary disease are evident in addition to central cyanosis, which becomes more intense with crying. Diagnosis depends on the presence of arterial oxygen gradient above 20 mm Hg between a preductal (right radial artery) and a postductal (umbilical artery) samples. Doppler echocardiography can demonstrate the shunt and measure the elevated pulmonary blood pressure.
6. **Pneumothorax:** It may occur spontaneously during the course of illness of a severe pulmonary disease as hyaline membrane disease, meconium aspiration, diaphragmatic hernia or congenital lobar emphysema. More commonly, it is iatrogenic and follows vigorous resuscitative measures or mechanical ventilation. Clinically, sudden deterioration of the condition with cyanosis, pallor or skin mottling should raise the possibility. Chest examination reveals diminished air entry over the involved side with inediastinal shift to the other side. Transillumination of the thorax is often helpful in emergency situations. Urgent chest X-ray is diagnostic and it reveals hyper-transradiant hemithorax with absent bronchovascular markings (see Basic Pediatric Radiology).
7. **Diaphragmatic hernia:** Herniation of abdominal viscera into the thoracic cavity (mostly on the left side through the Foramen of Bochdalek) may result in severe respiratory distress at birth or later in neonatal period or infancy. Chest auscultation reveals diminished air entry over the involved side with mediastinal shift to the other side. Respiratory distress in conjunction with scaphoid abdomen should always raise the possibility. Chest X-ray is usually diagnostic where multiple cysts (air-filled bowel) occupying one hemithorax and pushing the mediastinum to the other side are demonstrated. Pneumothorax is a common complication.

8. **Congenital lobar emphysema:** It is caused by partial obstruction of a bronchus by external (cyst or aberrant vessel) or internal (plugs, mucosal folds or stenosis) conditions. The left upper lobe is the most commonly involved (50% of cases), followed by the right middle lobe (30%) and right upper lobe (20%). Half the cases are symptomatic in neonatal period but usually not during the first week. Clinical diagnosis is difficult but chest X-ray usually demonstrates the emphysematous lobe with mediastinal shift to the other side. Bronchoscopy is helpful in demonstrating the obstructed bronchus and in removing mucous plugs when it is the cause of obstruction. Treatment is surgical.
9. **Bronchopulmonary dysplasia (BPD):** It is a chronic lung disease that occurs principally in premature babies treated with mechanical ventilation for severe hyaline membrane disease. Clinically, instead of the natural improvement on the 3rd or 4th day, the condition deteriorates and respiratory distress persists for few or several weeks and the baby becomes ventilator and oxygen dependent. Chest auscultation may reveal fine crepitations and expiratory wheezing. Cor pulmonale and congestive heart failure commonly occur. Radiological findings are gradually changing over weeks.

Radiological stages of bronchopulmonary dysplasia

Stage I (first week): Ground glass appearance similar to hyaline membrane disease.

Stage II (second week): Generalized opacity and pulmonary plethora.

Stage III (third week) Bilateral multiple small cysts (bubbly lungs).

Stage IV (fourth week): Hyperinflation, widespread stranding, cardiomegaly.

Bronchopulmonary dysplasia should be differentiated from other causes of neonatal chronic lung disease characterized by chronic respiratory distress.

Causes of neonatal chronic lung disease

Bronchopulmonary dysplasia: Mainly in ventilated prematures.

Wilson-Mikity syndrome: Mainly in nonventilated very low birth weight babies.

Chronic pulmonary insufficiency of prematurity.

Chronic pneumonia: Chronic bacterial or viral interstitial pneumonia.

Recurrent aspiration: With tracheoesophageal fistula, gastroesophageal reflux.

Congenital lobar emphysema.

Heart failure due to patent ductus arteriosus.

10. **Other causes:** Several other conditions may lead to respiratory distress in the newborn. Bilateral choanal atresia leads to marked distress and cyanosis, which is relieved by crying. Diagnosis is confirmed by failure to pass a nasogastric tube through both nostrils. Pulmonary hypoplasia occurs in association with lung compression as diaphragmatic hernia or with oligohydramnios. Pulmonary atelectasis occurs in extreme prematurity (less than 28 weeks). Massive pulmonary hemorrhage is a form of hemorrhagic pulmonary edema that complicates cases of severe hypoxia, hypothermia, hypoglycemia, pneumonia and coagulation defect

as DIC. The onset is usually between the second and fourth day after birth where a red frothy fluid is aspirated from the mouth or from the endotracheal tube in ventilated babies. Auscultation of the chest reveals widespread crepitations. Cystic adenomatoid malformation is a rare form of congenital cystic disease of the lung. The multiple cysts may be large, medium-sized or small. The condition should be differentiated from other causes of multiple cysts especially diaphragmatic hernia, bronchopulmonary dysplasia and multiple pneumatoceles of staphylococcal pneumonia. Other lung cysts as bronchogenic cyst and sequestration cyst are very rare.

Extrapulmonary Causes

1. **Congestive heart failure:** Clinical diagnosis of congestive heart failure depends on the presence of the cardinal triad of 3 T (tachycardia, tachypnea and tender liver). Diagnosis of the cause can be made by clinical evaluation and echocardiography. Presence of central cyanosis and/or significant murmur suggests a congenital heart disease. Hypoxia or shock indicates a myocardial ischemia while manifestations of sepsis indicates a myocarditis.

Cardinal clinical triad of congestive heart failure

Tachycardia: Heart rate above 180/minute.

Tachypnea: Respiratory rate above 60/minute.

Tender liver: The liver is enlarged and tender.

2. **Metabolic acidosis:** Clinical diagnosis of metabolic acidosis depends on the presence of deep rapid respiration (acidotic breathing). In more severe cases, disturbed consciousness becomes evident. Clinical suspicion should be confirmed by blood gas analysis where all parameters are low (pH, bicarbonate and PaCO_2). The severity of acidosis can be determined by the degree of lowering of pH and serum bicarbonate level.

Normal blood gases in newborn

Grades of metabolic acidosis

Parameter	Value	Grade	pH	Bicarbonate
pH	7.35 - 7.4	Mild	Below 7.3	Below 16 mEq/liter
Bicarbonate	20 - 24 mEq/liter	Moderate	Below 7.2	Below 13 mEq/liter
PaCO_2	35 - 40 mm Hg	Severe	Below 7.1	Below 10 mEq/liter
PaO_2	60 - 80 mm Hg	Profound	Below 7.0	Below 7 mEq/liter

- For assessment of acid-base status, venous samples are satisfactory.

The cause of acidosis can be identified by the clinical evaluation (hypoxia, sepsis, shock), evaluation of renal function (renal failure), aminogram (errors of metabolism) and calculation of the anion gap (normal in renal tubular acidosis and high in other causes of metabolic acidosis).

Anion gap = Serum sodium - (serum chloride + serum bicarbonate) = 5 - 15 mEq/litre.

3. **Severe anemia or polycythemia:** Measurement of hemoglobin level and hematocrit value should be a routine in every case of neonatal respiratory distress. *Severe acute anemia* (hemoglobin below 8 gm/dl) may result from severe hemolysis or severe blood loss. *Polycythemia* (hematocrit over 65%) may result from delayed cord clamping, maternofetal transfusion or placental insufficiency secondary to intrauterine hypoxia. The most common clinical manifestations of polycythemia are plethora, cyanosis, respiratory distress, lethargy, jaundice and poor suckling.

MANAGEMENT

Neonates with respiratory distress should be admitted to a neonatal intensive care unit where facilities for assisted ventilation are available. Initial investigations should include chest X-ray, blood gases, hemoglobin level, sepsis screen and possibly echocardiography.

Significance of investigations in neonatal respiratory distress

Chest X-ray: In ALL cases (To distinguish between different pulmonary causes).
 Blood gases: In ALL cases (To detect metabolic acidosis and respiratory failure).
 Hemoglobin level and hematocrit value: To detect anemia and polycythemia.
 Sepsis screen (CBC, ESR, CRP): With suspected pneumonia.
 Echocardiography: With suspected congenital heart disease.

Monitoring, respiratory support and specific treatment of the causative disease form the foundation of management of neonatal respiratory distress.

Respiratory monitoring

Repeated assessment of the severity of illness is an essential step and recording of the obtained data in a "flow sheet" is important for proper evaluation of the course of illness. Respiratory monitoring can be both clinical and laboratory.

1. **Clinical monitoring:** Repeated assessment of the degree of respiratory distress and chest findings is important. Continuous display of heart rate and respiratory rate with a "monitor" is preferable as cardiopulmonary arrest may occur unexpectedly and may follow stressful procedures as suctioning or endotracheal intubation.
2. **Arterial oxygen saturation by "pulse oximeter":** Repeated or continuous measurement of arterial oxygen saturation is a simple, noninvasive and reliable bedside method for assessment of the degree of hypoxemia. In the newborn, the probe of the pulse oximeter is placed over the whole foot. Normal saturation is above 95% and values below this level indicates hypoxemia, which can be mild (90-95%), moderate (85-90%) or severe (below 85%).
3. **Arterial blood gases (ABG):** Repeated measurement of arterial blood gases is the most sensitive and reliable method for assessment of the state of oxygenation, state of ventilation and state of acid-base balance. Respiratory failure is a PaO_2 below 50 mm Hg with or without PaCO_2 above 50 mm Hg (for details of interpretation of arterial blood gases, see respiratory distress). Transcutaneous measurement of

oxygen and carbon dioxide (TcPO_2 , TcPCO_2) is a simple noninvasive procedure, which allows continuous monitoring of PO_2 and PCO_2 and reduces the necessity of repeated arterial sampling.

Respiratory distress should not be confused with respiratory depression as both can lead to cyanosis and respiratory failure.

Neonatal respiratory failure

	Lung failure (Type I RF) (Respiratory distress)	Pump failure (Type II RF) (Respiratory depression)
Causes	Pulmonary causes Extrapulmonary causes	CNS narcosis: Drugs, anesthesia Severe brain insult Severe pulmonary disease
Clinically	Tachypnea \pm retractions, grunting, cyanosis.	Slow irregular respiration with frequent apnea, cyanosis. Disturbed consciousness.
Blood gases	Lung failure (Type I RF) • Arterial hypoxemia (low PaO_2) \pm hypoventilation (high PaCO_2)	Pump failure (Type II RF) • hypoventilation (high PaCO_2) \pm hypoxemia (low PaO_2)
Therapy	• Oxygen therapy \pm Assisted ventilation	• Assisted ventilation \pm Oxygen therapy

- Acute respiratory failure is always associated with acute respiratory acidosis (low pH, high bicarbonate) or combined respiratory and metabolic acidosis (very low pH, normal bicarbonate).

Respiratory support

The principal goal of respiratory support is to ensure adequate oxygenation and ventilation. In mild to moderate cases, oxygen therapy and clearing of respiratory passage through suctioning may be sufficient. In severe cases, positive pressure support by continuous positive airway pressure or assisted ventilation is life-saving.

- 1. Oxygen therapy:** Oxygen administration is the most simple and most essential element in respiratory support. It is indicated in all cases of respiratory distress. It aims to relieve cyanosis and to correct arterial hypoxemia. It is either given inside the incubator or by using a head box. Oxygen should be given in a concentration that relieves cyanosis, keeps arterial oxygen saturation above 90% and PaO_2 between 60-80 mm Hg. Practically, therapy starts with 40-60% concentration which can then be changed (increased or decreased) according to the response. Cyanosis is an indication to 100% oxygen. Persistent low oxygen saturation (below 90%) and low PaO_2 (below 50 mm Hg) in spite of 70% oxygen is an indication of positive pressure support.
- 2. Continuous positive airway pressure (CPAP):** This form of continuous pressure support is indicated in persistent hypoxemia and low oxygen saturation in spite of 70% oxygen. CPAP can be provided through a nasal catheter (basal CPAP), nasopharyngeal tube (nasopharyngeal CPAP) or endotracheal tube (endotracheal

CPAP). A constant pressure of 4-6 cm water is usually used in addition to 40-70% oxygen. High pressures above 7-8 cm water can lead to pneumothorax (stretch injury).

3. **Assisted ventilation:** This form of intermittent pressure support is indicated in CPAP failure, hypoventilation (PaCO_2 above 50-60 mm Hg), severe respiratory acidosis or frequent apnea. Manual ventilation with the bag and mask is the simplest form, which can be used when facilities for mechanical ventilation are not available. It can be given for few minutes every 15-20 minutes. Mechanical ventilation (IMV or CMV) is more efficient and it aims to ensure adequate oxygenation and ventilation.

Specific treatment

Treatment of the causative disease and the possible associated complications should go parallel to the nonspecific respiratory support. For instance, decompression of the collapsed lung by a closed intercostal drainage is life-saving in case of pneumothorax. The main lines of therapy are the following:

1. **I.V. fluid therapy:** It is indicated in all neonates with respiratory distress during the first few days and it aims to provide the daily requirements of water, electrolytes and calories. The amount given in the first day after birth is 75 ml/kg/day and it is formed of glucose 10%. From the second day, a maintenance therapy is given (90 ml/kg/day) and the amount is increased in the following days (10 ml/kg/day) until a total daily intake of 150 ml/kg/day is reached. If I.V. fluid therapy is needed for more than 3 days, nasogastric tube feeding should be started to gradually replace I.V. fluids.
2. **Antibiotic therapy:** Since differentiation between hyaline membrane disease and neonatal pneumonia may be initially difficult, combined parenteral antibiotic therapy is indicated until a bacterial infection is excluded. A combination of ampicillin (100 mg/kg/day, I.V. divided into 3-4 doses) and gentamicin (6 mg/kg/day, I.V. divided into 2-3 doses) is a satisfactory initial combination. Ampicillin may be substituted with broad-spectrum penicillin with extended activity (as sultamicillin or co-amoxiclav) or with antipseudomonal activity (as piperacillin). Gentamicin may also be substituted with other aminoglycosides as tobramycin or amikacin. In severe cases, a third generation cephalosporin as cefotaxime (100 mg/kg/day, I.V. in 2 divided doses) may be added (see also neonatal sepsis).
3. **Surfactant therapy:** It may be used in very low birth weight infants with severe hyaline membrane disease. It is given through the endotracheal tube in a dose of 5 ml/kg, and the dose may be repeated after 12 hours if the response is inadequate. The available preparation (Exosurf vial) is very expensive.
4. **Treatment of complications:** Persistent metabolic acidosis necessitates therapy with sodium bicarbonate (3 ml/kg, slow I.V. of the 5% solution) and cardiogenic shock due to severe myocardial anoxia requires inotropic support with dopamine infusion. Anemia or polycythemia should also be corrected. Duct-dependant CHD requires prostaglandin E_1 infusion (see cardiac emergencies).

5. **Surgical intervention:** *Pneumothorax* necessitates immediate thoracocentesis and closed intercostal drainage. In case of diaphragmatic hernia, surgical correction after initial stabilization is indicated. Congenital lobar emphysema causing persistent respiratory distress requires surgical excision of the affected lobe. Tracheo-esophageal fistula causing aspiration pneumonia also requires surgical correction. Bilateral choanal atresia is occasionally the cause of distress and surgical correction is necessary to open the airway.

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Chapter

Neonatal Convulsions

Diagnosis

Characters of convulsions

Types of convulsions
Onset of convulsions
Duration and frequency
Response to therapy

Causes of convulsions

Brain damaged convulsions
Metabolic convulsions

Management

Control of convulsions

Phenobarbital (20 mg/kg)
Phenytoin (20 mg/kg)
± Diazepam (0.5 mg/kg)

Treatment of the cause

Metabolic convulsions
Meningitis

Treatment of complications

Convulsions in the newborn are common serious problems that occur in about 2% of full terms and up to 10% of very low birth weight babies. Hypoxic-ischemic encephalopathy is by far the most common cause (50% of cases) followed by intracranial hemorrhage (20%), neonatal meningitis (10%) and metabolic causes as hypoglycemia and hypocalcemia (10%). Most cases occur during the first week after birth and particularly during the first few days.

DIAGNOSIS

Diagnosis of neonatal convulsions should include the characters of convulsions and the causative disease. It is important to remember that prompt control of convulsions should precede any diagnostic considerations.

Characters of convulsions

Description of convulsions should include the type, onset, duration and frequency, and the response to therapy.

1. Type of convulsions: Neonatal convulsions can be classified into five types:

- a. **Subtle:** It is the commonest type (50% of cases). It may include oral movements (sucking, chewing or yawning), eye movements (repetitive blinking, nystagmus or tonic horizontal deviation), limb movements (bicycling or pedaling) or respiratory movements (irregular breathing or apnea). Apnea due to subtle fits is usually associated with tachycardia or normal heart rate while apnea due to other causes is usually associated with bradycardia.

- b. **Focal clonic:** It is a rhythmic twitching of muscle groups especially in the face and extremities with focal distribution.
- c. **Multifocal clonic:** Several muscle groups are involved simultaneously.
- d. **Tonic:** It is a rigid posturing of extremities and trunk (decorticate or decerebrate) that may be focal or generalized and may be associated with clonic movements or apnea.
- e. **Myoclonic:** It is a brief focal or generalized jerks of extremities or body mainly in the distal muscle groups.

Tonic and myoclonic fits have a poor prognosis as they reflect a diffuse CNS disease or intraventricular hemorrhage. Subtle and clonic fits have a better prognosis.

Convulsions should not be confused with jitteriness, which is commonly seen in normal newborns or in association with hypoglycemia, hypocalcemia, hypoxia or in infants of diabetic mothers. Jitteriness is a tremor-like movements that is usually precipitated by sensory stimuli and can be stopped by holding the infant's extremity. It is not associated with abnormal eye movements or LEG abnormalities.

2. **Onset of convulsions:** Convulsions occurring immediately after birth may be due to dilutional hyponatremia or drug-withdrawal. Convulsions during the first day is mostly due to hypoxic-ischemic encephalopathy or metabolic causes as hypoglycemia or hypocalcemia. In intracranial hemorrhage, the onset of convulsions is usually after the first day and in meningitis, it is usually not during the first few days. Convulsions that appear after 3 - 4 days in an infant who was normal at birth and was fed normally before the onset of convulsions should suggest errors of metabolism. Convulsions after the first week are mostly due to meningitis or late-onset hypocalcemia.
3. **Duration and frequency of convulsions:** Fits may be very transient (lasting for seconds), transient (lasting for few minutes), short (lasting for 5-15 minutes) or prolonged (more than 15 minutes). Fits may also be infrequent (just few fits), frequent (recurring several times per day) or very frequent (recurring every hour or less). Prolonged and very frequent fits have a poor prognosis.
4. **Response to therapy:** Fits can be easily controllable, difficult to control or intractable (not responding to combined anticonvulsant therapy). The prognosis of intractable fits and fits persisting for more than 3 days is generally poor.

Cause of convulsions

Clinical differentiation between brain damaged and metabolic convulsions depends on four clinical criteria—type of convulsions, associated neurological findings, general condition and respiratory pattern.

1. **In brain damaged convulsions,** convulsions are usually tonic and may be clonic also. Other neurologic signs are usually present as disturbed consciousness (lethargy or coma), increased intracranial pressure (bulging fontanel), lateralizing signs

(unequal pupils or focal motor weakness) or meningeal irritation (neck retraction and/or arched back). The baby looks sick with poor activity, weak or absent suckling and vomiting. In advanced cases, there is respiratory depression with slow irregular respiration and apneic spells.

- 2. **In metabolic convulsions**, convulsions are usually clonic and the baby does not look sick except in hypoglycemia and errors of metabolism. There are no other neurological findings and no respiratory depression.
- 3. **Both conditions** may coexist in the same patient. Hypoglycemia and/or hypocalcemia are commonly present in patients with hypoxic-ischemic encephalopathy and intracranial hemorrhage.

Although the cause can be suggested in many cases, some investigations are required to confirm the diagnosis.

Possible investigations of neonatal convulsions

Blood sugar, calcium, magnesium and sodium: In all cases.
Cranial ultrasonography or CT scan: In brain damaged convulsions.
Lumbar puncture and CSF examination: In suspected meningitis.
Sepsis screen (CBC, ESR, CRP, blood culture): In suspected septicemia or meningitis.
Metabolic screen (acid-base balance, ammonia level, aminogram): In suspected errors of metabolism or in unexplained convulsions.

BRAIN DAMAGED CONVULSIONS

- 1. **Hypoxic-ischemic encephalopathy**: It is by far the commonest cause (50% of cases). It occurs in infants exposed to perinatal hypoxia, which results in brain edema and encephalopathy. The patient usually presents with low Apgar score and cyanosis at birth. Convulsions usually start within 12 hours after birth and usually last for few days. Other neurological findings and respiratory depression are present with variable degrees according to the severity and the duration of hypoxia. Other manifestations of hypoxia may also be present (see below). Prognosis is generally good in mild to moderate cases. In severe cases characterized by prolonged fits and coma, death or severe neurological sequelae (epilepsy, motor and intellectual deficits) may occur. Cranial ultrasonography or CT scan is important to demonstrate brain edema and to exclude intracranial hemorrhage.

Clinical staging of hypoxic-ischemic encephalopathy

Sign	Mild (stage 1)	Moderate (stage 2)	Severe (stage 3)
Convulsions	No	Short fits	Prolonged fits
Consciousness	Hyperalert	Lethargy	Coma
Muscle tone	Normal	Hypotonia	Flaccidity
Suckling	Weak	Poor	Absent

- 2. **Intracranial hemorrhage**: It is the second most common cause of neonatal convulsions (20% of cases). It occurs principally in three groups of patients: those with severe prematurity, severe perinatal hypoxia and severe birth trauma to the

head. Occasionally, bleeding may follow disseminated intravascular coagulation or congenital vascular anomalies. Bleeding may occur in one or more of the following five sites (epidural, subdural, subarachnoid, intracerebral and intraventricular). Intraventricular hemorrhage (IVH) is the most serious and most common site especially in prematures and in those with severe hypoxia. In addition to the clinical findings of hypoxic-ischemic encephalopathy, intracranial hemorrhage should be considered in the following clinical situations: (1) Onset of signs in the second or third day, (2) Persistence of convulsions and other neurological signs for more than a few days, (3) Presence of lateralizing signs as unequal pupils and focal paralysis, (4) Progressive pallor and fall in hemoglobin level. Cranial ultrasonography or CT scan is important for diagnosis, localization and grading of severity. Prognosis is generally poor and it depends on the site and extent of hemorrhage. Mortality rate is high and neurological sequelae (epilepsy, motor and intellectual deficits) are very common in survivors.

Multiple organ system dysfunction of hypoxia

System	Effects
Respiratory	Pulmonary hypertension, pulmonary hemorrhage.
Cardiovascular	Myocardial ischemia, cardiogenic shock.
Neurologic	Hypoxic-ischemic encephalopathy, intracranial hemorrhage.
Metabolic	Acute renal Failure (acute tubular or cortical necrosis). Hypoglycemia, hypocalcemia, hyponatremia.
Hematologic	Disseminated intravascular coagulation (DIC).
Digestive	Perforation, ulceration, hemorrhage.

- Neonatal meningitis:** It is the third most common cause of neonatal convulsions (10% of cases). It occurs at any time during the neonatal period but usually not during the first few days. It may accompany cases of neonatal septicemia especially those of late onset sepsis. It may also follow infected wounds or infected meningomyelocele. Clinical manifestations start with nonspecific features as poor suckling, vomiting, irritability and fever or hypothermia. The classic signs appear late and include convulsions, disturbed consciousness and increased intracranial pressure (bulging fontanel). Lumbar puncture and CSF examination is important for diagnosis. Other laboratory tests as CBC, ESR and CRP are also important (see neonatal sepsis). Prognosis depends on the time of diagnosis and efficacy of antibiotic therapy.
- Kernicterus:** It occurs as a complication of severe neonatal hyperbilirubinemia when serum bilirubin exceeds the critical level (20 mg/dl in full terms and lower values in low birth weight babies). Untreated Rh disease is the commonest cause. Clinical manifestations usually appear between 3 - 6 days after birth. In addition to deep jaundice, the baby looks very sick with poor suckling, vomiting and absent Moro reflex. Twitches and convulsions then follow with characteristic spasms and rigidity (opisthotonos). Mortality rate is very high (75%) and the remainders develop cerebral palsy in late infancy and early childhood.

5. **Cerebral anomalies:** Rarely, neonatal convulsions may reflect an underlying structural anomaly as lissencephaly, schizencephaly, holoprocencephaly or neonatal adrenoleukodystrophy. A neurocutaneous syndrome as tuberous sclerosis may be the cause of intractable convulsions. CT scan of the head or magnetic resonance imaging (MRI) is essential for diagnosis of various cerebral anomalies.

METABOLIC CONVULSIONS

1. **Hypoglycemia:** It occurs mainly in low birth weight babies, infants of diabetic mothers, infants of toxemic mothers and in sick neonates (hypothermia, hypoxia or sepsis). Persistent or recurrent hypoglycemia should suggest errors of metabolism as galactosemia, glycogen storage disease or maple syrup urine disease. Clinical manifestations usually appear during the first few days and include jitteriness, convulsions and disturbed consciousness. Episodes of central cyanosis, apneic spells and heart failure may be so evident to a degree suggesting congenital cyanotic heart disease. Unlike other common metabolic causes, the baby looks sick with poor activity and weak or absent suckling. Diagnosis is confirmed by the presence of low blood sugar level (below 30 mg/dl) and disappearance of symptoms with I.V. glucose administration (2 - 4 ml/kg of glucose 10%).
2. **Hypocalcemia:** It may appear early (in the first few days) or late (after the first week). *Early hypocalcemia* occurs mainly in premature babies, infants of diabetic mothers and in association with severe perinatal hypoxia. *Late hypocalcemia* occurs in some infants receiving cow milk due to the high phosphate content. The baby looks generally well in spite of the muscular twitches, jitteriness and convulsions. Diagnosis is confirmed by the presence of low serum calcium level (below 6 mg/dl). Failure of response to I.V. calcium gluconate should suggest an associated condition especially hypoxic-ischemic encephalopathy or hypomagnesemia.
3. **Hypomagnesemia:** It is less common than hypoglycemia and hypocalcemia. It occurs mainly in low birth weight babies, infants of diabetic mothers and in those receiving intravenous fluids without supplementation of magnesium. It should also be suspected in every case of convulsions with normal glucose and calcium level or in case of tetany not responding to intravenous calcium. Diagnosis is confirmed by low serum magnesium level (below 1.5 mg/dl). It responds to I.V. magnesium (1.0 ml/kg of magnesium sulphate 10%). Primary hypomagnesemia is a rare condition characterized by defective intestinal absorption of magnesium. Tetanic spasms starting in neonatal period or early infancy and not responding to I.V. calcium is the main presentation.
4. **Dilutional hyponatremia:** It occurs in infants born to mothers who received a large amount of intravenous hypotonic solutions shortly before birth. It may also occur in infants with renal salt losses, inappropriate secretion of antidiuretic hormone or those receiving hypotonic I.V. fluids. Diagnosis is confirmed by low serum sodium level (below 120 mEq/litre). It responds to I.V. sodium chloride solution 3%.

5. **Hypernatremia:** It may occur with dehydration or iatrogenic due to excessive bicarbonate therapy or hypertonic solutions. Diagnosis is confirmed by high serum sodium level (above 150 mEq/litre).
6. **Errors of metabolism:** Although uncommon, errors of metabolism should be considered in any infant who is normal at birth and becomes symptomatic after a few days of milk intake. Symptoms include poor feeding, vomiting, lethargy and convulsions. The condition may progress rapidly to deep coma. Three categories of amino acid disorders should be considered: (1) Amino acidopathies as maple syrup urine disease, phenylketonuria and nonketotic hyperglycemia, (2) Organic acidemia as propionic acidemia and methylmalonic acidemia, (3) Urea cycle disorders with hyperammonemia as argininemia, citrullinemia and argininosuccinic acidemia. Laboratory approach for diagnosis should initially include plasma ammonia level and acid-base status:
 - Hyperammonemia without acidosis suggests urea cycle disorders.
 - Metabolic acidosis (with or without hyperammonemia) suggests organic acidemia.
 - Normal ammonia and pH suggests amino acidopathies.
(Aminogram is necessary for precise diagnosis).
7. **Drugs:** Withdrawal convulsions may occur in infants born to mothers receiving large doses of sedatives or hypnotics. Clinical manifestations also include tremors, poor feeding, yawning and sneezing. Convulsions may also occur with some drugs given to the baby especially theophylline.
8. **Toxins:** Convulsions may occur with any severe infection especially septicemia. Other clinical manifestations suggesting sepsis are usually evident. Tetanus neonatorum occurs due to infection with clostridium tetani organism usually at birth during cutting the cord under poor hygienic conditions. The infection remains localized at the umbilicus producing powerful exotoxins, which are absorbed through motor end plates or lymphatics and produce the characteristic picture. Clinical manifestations appear after an incubation period of about one week and start with trismus (lock jaw) and difficult milk intake. Clonic convulsions and characteristic spasms rapidly appear with stiff extremities, neck retraction and arched back (opisthotonos). Convulsions and spasms are characterized by the following: (1) can be precipitated by the slightest stimulus (hyperexcitability), (2) intermittent early and separated by complete relaxation, (3) spasms are painful as the consciousness is not impaired, (4) may lead to intramuscular hemorrhage, fracture spine and laryngeal spasm and death. Umbilical sepsis is usually evident. Diagnosis is clinical and it depends on the characteristic picture. Lumbar puncture and CSF examination is normal.

MANAGEMENT

Newborns with early-onset convulsions should be hospitalized in a neonatal intensive care unit for control of convulsions, treatment of the causative disease and treatment

of complications especially the increased intracranial pressure secondary to brain edema or intracranial hemorrhage. Initial investigations should include blood sugar level, serum electrolytes, CSF examination and cranial ultrasonography.

Control of convulsions

Following the basic ABC (airway, breathing, circulation), immediate control of convulsions is made by I.V. anticonvulsants. Phenobarbital (15-20 mg/kg, I.V.) or phenytoin (15-20 mg/kg, I.V.) is initially given to control the ongoing convulsive fits. Both drugs may be needed in severe cases. Prevention of further fits is made by a maintenance dose of phenobarbital (3 mg/kg/dose, I.V. every 12 hours) and/or phenytoin (3 mg/kg/dose, I.V. every 12 hours). Maintenance anticonvulsant therapy may be continued for several days and until recurrence becomes unlikely. Withdrawal should be gradual. It is important to remember that in comatose patients, oxygen therapy (40%) should continue until the baby becomes fully conscious.

Treatment of the cause

Metabolic convulsions should be corrected with the appropriate drug therapy (see below). In neonatal meningitis parenteral combined antibiotic therapy for up to three weeks is indicated (see neonatal sepsis). Tetanus neonatorum necessitates therapy with antitetanic serum (50,000 unit, I.V. and 50,000 unit, I.M.). When a coagulation defect is the cause of intracranial hemorrhage, it should be urgently corrected.

Treatment of metabolic convulsions

Hypoglycemia: 1-2 ml/kg of glucose 25%, I.V. over 1 minute.

Hypocalcemia: 2 ml/kg of calcium gluconate 10%, I.V. over 10 minutes.

Hypomagnesemia: 2 ml/kg of magnesium sulphate 10%, I.V. over 20 minutes.

Hypонатremia: 5 ml/kg of sodium chloride 3%, I.V. over 20 minutes.

Treatment of complications

In newborns with brain-damaged convulsions, increased intracranial pressure due to cytotoxic brain edema is a common complication. Clinical manifestations include bulging fontanel, disturbed consciousness, tonic fits, sluggish pupillary reaction to light and increased muscle tone. Rapid measures to reduce the increased ICP include, (1) head elevation 30° in neutral position, (2) mechanical hyperventilation to keep PaCO₂ just below 30 mm Hg, and (3) mannitol therapy (5 ml/kg of 20% solution, I.V. over 30 minutes, every 6 hours). Slow measures to reduce the increased ICP include; (1) furosemide therapy (0.5-1.0 mg/kg, I.V. every 4-6 hours), (2) fluid restriction (50-60% of daily maintenance requirements), and (3) steroid therapy (dexamethasone 0.25 mg/kg, I.V. every 6-12 hours). Surgical measures may be indicated in selected cases of intracranial hemorrhage (for details of therapy, see neurologic emergencies).

Nutritional support

It is important to remember that nasogastric tube feeding was originally designed for comatose patients. From the second day of illness, nasogastric tube feeding should gradually replace the I.V. fluids. Oral feeding only resumed after the patient becomes fully conscious.

43 Chapter

Neonatal Sepsis or Septicemia

Diagnosis

Clinical diagnosis

Early manifestations
Late manifestations

Laboratory confirmation

Nonspecific findings
Causative organism

Management

Antibiotic therapy

Initial therapy
Subsequent therapy

Other lines of therapy

Transfusion therapy
Treatment of complications

Neonatal sepsis or septicemia is a clinical syndrome resulting from a serious infection in the first month of life. It is a common serious problem with mortality rate ranging from 10 to 40%. In early onset disease, the infection is mostly acquired from the mother and clinical manifestations appear during the first three days or up to the 7th day. It is mainly caused by organisms present in the cervix or vaginal canal. In late onset and nosocomial disease, the infection is acquired postnatal from the community or the hospital and clinical manifestations appear after the first three days or the first week. It is mainly caused by other more virulent organisms as *Staphylococcus* and *Pseudomonas*. Nonbacterial infections with viruses (herpes simplex, cytomegalovirus) and fungi (candida albicans) may be the cause of late onset sepsis.

Causative organisms and risk factors in neonatal sepsis

Early onset sepsis

Main causative organisms

Group B *Streptococcus*
Escherichia coli
Listeria monocytogenes
Hemophilus influenza
Klebsiella
Streptococcal pneumoniae

Main risk factors

Premature rupture of membranes
Maternal fever or leukocytosis
Uterine tenderness
Chorioamnionitis
Resuscitation with ET tubes

Late onset and nosocomial sepsis

Main causative organisms

Staphylococcus aureus, *S. epidermidis*
Pseudomonas aeruginosa
Klebsiella
Viral (herpes simplex, cytomegalovirus)
Candida albicans
Other organisms as early onset sepsis

Main risk factors

Hospitalization
Endotracheal intubation
Mechanical ventilation
Umbilical catheterization, sepsis
Total parenteral nutrition, tube feeding

- Prematurity is a risk factor in both groups and it is associated with 5-10 times greater risk of sepsis.

DIAGNOSIS

It should be emphasized that diagnosis of neonatal sepsis is a clinical diagnosis, which can be confirmed by laboratory investigations.

- **Clinical suspicion** should be considered in presence of the risk factors. Presence of more than one risk factor especially in association with prematurity makes sepsis more likely. The condition should also be suspected in any mechanically ventilated baby who shows a clinical deterioration or persistent metabolic acidosis.
- **Early manifestations** of neonatal sepsis are usually vague and nonspecific. The condition should be considered in any baby who is not doing well or sick with lethargy, poor suckling, vomiting, fever or hypothermia. In these clinical situations, hospitalization, investigations and immediate parenteral combined antibiotic therapy are indicated.
- **Late manifestations or complications** of neonatal sepsis are usually related to different systems. Serious focal infections may become evident as CNS (meningitis), respiratory (pneumonia), urinary (pyelonephritis), digestive (hepatitis, necrotizing enterocolitis) or skeletal (septic arthritis). Careful search for all these infections should be made. Septic arthritis of the hip should be considered when the movement of one lower limb is limited or painful and diagnosis can be confirmed by ultrasound. Other serious manifestations or complications should be expected and excluded.

Late manifestations or complications of neonatal sepsis

Serious focal infections: Meningitis, pneumonia, pyelonephritis, hepatitis, septic arthritis.
 Septic shock: Cold extremities, skin mottling, poor capillary refill, tachycardia, hypotension.
 Septic renal failure: Oliguria, edema, acidotic breathing.
 Serious bleeding (DIC): Purpura, bleeding from puncture sites, necrotic skin patches.
 Sclerema: Skin hardening starting over limbs and extending to trunk and face. It is fatal.

Laboratory investigations

With clinical diagnosis of neonatal sepsis, laboratory investigations are indicated to confirm the diagnosis and to identify the causative organism.

Laboratory confirmation is usually made by simple tests as complete blood count (CBC), erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). Positive 2 tests indicate infection in 90% of cases and 3 tests in 97% of cases.

Laboratory findings suggestive of neonatal sepsis

Total white cell count below 5000/mm³ or above 30000/mm³.
 Band count above 10% or band/total neutrophil ratio above 0.2.
 Toxic granulations in neutrophils.
 ESR above 15 mm/first hour.
 CRP above 20 mg/litre.
 Elevated serum level of cytokines (as interleukin-6 and interleukin-8).

Identification of the causative organism is made by appropriate cultures (blood, urine, CSF and tracheal aspirate). It is important to emphasize that positive cultures are not necessary for diagnosis especially when clinical suspicion is considerable and nonspecific laboratory tests are suggestive.

MANAGEMENT

Newborns with suspected neonatal sepsis should be hospitalized for observation (vital signs, level of consciousness, suckling power), investigations (CBC, CRP, ESR, blood culture) and immediate treatment. Management includes the following aspects.

1. Antibiotic therapy: It is the principal line of therapy and it should be started immediately without waiting for results of investigations.

- **Initial therapy:** Initial parenteral combined therapy with ampicillin (100 mg/kg/day, I.V. divided into 3-4 doses) and gentamicin (6 mg/kg/day, I.V. divided into 2-3 doses) is satisfactory. Ampicillin can be substituted with other broad-spectrum penicillins with antipseudomonal activity as piperacillin and gentamicin may also be substituted with other aminoglycosides as tobramycin or amikacin. In severe cases, a third generation cephalosporin as cefotaxime (100 mg/kg/day, I.V. in 2 divided doses) may also be added. When the possibility of anaerobic infection is considerable, metronidazole (7.5 mg/kg/dose, I.V. every 12 hours) can be used.
- **Subsequent change:** Subsequent change of antibiotic therapy can be made according to the results of culture-sensitivity studies. Ceftazidime (100 mg/kg/day, I.V. in 2 divided doses) is the drug of choice for pseudomonas infection and vancomycin (40-60 mg/kg/day, I.V. in 3-4 divided doses) is the drug of choice for staphylococci.
- **Duration:** The minimum duration of antibiotic therapy is 2 weeks in septicemia and 3 weeks in meningitis. As a rule, it should be continued for 5-7 days after apparent clinical cure.

2. Antifungal therapy: Suspected or proved systemic candidiasis (positive blood culture) necessitates antifungal therapy with fluconazole in a dose of 3-6 mg/kg/day, I.V. in 2 divided doses. Available preparation is Diflucan I.V. infusion (100 mg/50 ml). Duration of therapy depends on the clinical and laboratory response.

3. Transfusion therapy: Whole blood transfusion or exchange transfusion may be considered in severe cases especially when complicated with DIC.

4. I.V. immunoglobulins: It may be used in severe cases to improve the host response. It is given in a dose of 300 mg/kg (10 ml/kg), I.V. infusion (over 6-8 hours), daily for 5 days.

5. Treatment of complications: The main complications of severe septicemia are septic shock, acute renal failure, shock lung and DIC. Immediate management of any complication, when present, is important.

6. Nutritional support: The initial maintenance I.V. fluid therapy should be gradually replaced by nasogastric tube feeding. Oral feeding can be resumed in infants with good suckling power.

44 Chapter

Early-onset Neonatal Jaundice

Diagnosis

Clinical diagnosis
Laboratory diagnosis

Management

Exchange transfusion
Phototherapy

Jaundice in the newborn is a very common problem, which can be physiological or pathological. In early onset jaundice, jaundice appears during the first week and usually subsides over one or two weeks. In late onset and persistent jaundice, jaundice either appears after the first week or persists for more than 2 - 3 weeks.

DIAGNOSIS

In early-onset neonatal jaundice, the main three causes are acute hemolysis, physiological jaundice and neonatal septicemia. Clinical differentiation depends on the onset and severity of jaundice, presence or absence of anemia, general condition (suckling power) and presence or absence of complications especially kernicterus.

Possible investigations of early onset jaundice

Serum bilirubin level (total, unconjugated, conjugated): In all cases.

Hemoglobin level, Coombs test, red cell morphology, reticulocytic count: In suspected hemolysis.

G6PD enzyme activity: In hemolysis not due to Rh or ABO incompatibility.

Sepsis screen (CBC, ESR, CRP, blood culture): In suspected septicemia.

- 1. Acute hemolysis:** In this condition, jaundice appears at birth or during the first day and it is commonly severe. Serum bilirubin level may rise rapidly to reach serious levels where kernicterus may occur. Anemia is evident clinically and hemoglobin level may reach below 6 gm/dl. The general condition is commonly affected especially with serious bilirubin levels. Kernicterus (see neonatal convulsions) is a real risk and it may occur when serum bilirubin exceeds the critical level, which depends on the birth weight and the condition of the baby. The critical level is lower in those with low birth weight and in sick neonates.

Critical indirect bilirubin level at which kernicterus may occur

Birth weight	Doing well baby	Sick baby
Above 2500 gm	20 mg/dl	18 mg/dl
2500 - 2000 gm	18 mg/dl	16 mg/dl
2000 - 1500 gm	16 mg/dl	14 mg/dl
1500 - 1250 gm	14 mg/dl	12 mg/dl
Below 1250 gm	12 mg/dl	10 mg/dl

- Manifestations of sickness include hypoxia, hypothermia, hypoglycemia, acidosis or infections.

The cause of hemolysis can be identified by clinical and laboratory evaluation.

- Rh incompatibility:*** It is the commonest cause of hemolysis. It occurs in some Rh positive babies born to Rh negative mothers. Hemolysis occurs due to placental passage of maternal antibodies active against the fetal red cells. The first baby is usually not affected as maternal sensitization usually occurs during delivery of the first baby. *Jaundice* and *anemia* are usually severe and the baby may be born with the picture of hydrops fetalis (pallor, edema and hepatosplenomegaly). Kernicterus is a common complication, which occurs when serum bilirubin exceeds the critical level. Diagnosis is confirmed by the presence of positive Coombs test, anemia (hemoglobin level below 10 gm/dl), reticulocytosis and unconjugated hyperbilirubinemia. Exchange transfusion is always necessary to keep serum bilirubin below the critical level.
 - ABO incompatibility:*** It is less common than Rh disease. The first baby may be affected. The disease is milder than Rh disease. Jaundice and anemia are not severe. Hydropsfetalis and kernicterus are rare. Coombs test may be negative. Diagnosis is confirmed by the presence of unconjugated hyperbilirubinemia and extensive spherocytosis.
 - Glucose 6 phosphate dehydrogenase (G6PD) deficiency:*** This X-linked disease is occasionally the cause of severe hemolysis and neonatal hyperbilirubinemia. The condition should be suspected in any male newborn with acute hemolysis not due to Rh or ABO incompatibility. Diagnosis is confirmed by the presence of low enzyme activity below 20 unit/ 10^{12} RBC (normal enzyme activity is 100-200 unit/ 10^{12} RBC).
 - Large cephalohematoma:*** Hemolysis may occur in a large cephalohematoma and leads to jaundice. The condition should be excluded in every case of anemia and jaundice.
2. **Physiological jaundice:** It is the commonest cause of jaundice as it occurs in up to 40% of normal newborns and 70% of prematures due to transient immaturity of hepatic conjugation of bilirubin and increased production of bilirubin following breakdown of fetal red cells. Jaundice appears in the second or third day and is usually not severe (less than 12 mg/dl in full terms and 15 mg/dl in prematures). It usually subsides within one week of onset. Anemia is absent and the general condition is fair with good activity and suckling power. Kernicterus does not occur, as serum bilirubin does not reach critical levels except in premature babies where

kernicterus may occur at lower levels. However, jaundice may be occasionally severe with serum bilirubin level above 15 mg/dl (exaggerated physiological jaundice). The main risk factors leading to exaggerated jaundice are male sex, race, cephalohematoma, polycythemia, breast-feeding and drugs as vitamin K₁. Physiological jaundice may also be prolonged and persists for more than 2 - 3 weeks.

3. **Neonatal septicemia:** Jaundice in septicemia, if present, usually appears between the fourth and seventh day or later and is usually moderate in severity. Anemia, if present, is usually not severe. The most important clinical signs are the markedly affected general condition. The baby is not doing well with lethargy, poor suckling, vomiting, fever or hypothermia. In severe cases, serious complications may occur as Septic shock, renal failure and DIC. With clinical suspicion, sepsis screen should be immediately made. It includes blood culture and other simple tests as complete blood count (CBC), erythrocyte sedimentation rate (ESR) and C-reactive protein (CRP). Immediate hospitalization and combined parenteral antibiotic therapy are important.

Laboratory findings suggestive of neonatal septicemia

Total white cell count below 5000/mm³ or above 30000/mm³.
 Band count above 10% or band/total neutrophil ratio above 0.2.
 Toxic granulations in neutrophils.
 Erythrocyte sedimentation rate (ESR) above 15 mm/first hour.
 C-reactive protein (CRP) above 20 mg/litre.

- Positive 2 tests indicate infection in 90% of cases and 3 tests in 97% of cases.
- Recently, elevated serum cytokines (as Interleukin-6 and interleukin-8) are highly suggestive.

MANAGEMENT

The main goal of management of unconjugated hyperbilirubinemia is to prevent kernicterus, which may occur when serum bilirubin level exceeds the critical bilirubin level (see above). Repeated measurements of serum bilirubin level are important especially when values near the critical level are obtained.

In most cases of physiological jaundice in term infants, serum bilirubin level is quite below the critical level and the condition subsides spontaneously without any therapy over 5-7 days. On the other hand, in severe hemolytic disease, serum bilirubin level rises rapidly and exchange transfusion and phototherapy are almost always indicated.

The decision to start therapy and the used method depends mainly on the bilirubin trend, which can be assessed by repeated measurements of serum bilirubin. For instance, a bilirubin level rising from 5 mg/dl to 15 mg/dl over 24 hours is serious because the bilirubin trend shows that critical levels can be reached during the next 24 hours. On the other hand, serum bilirubin level rising from 13 mg/dl to 15 mg/dl over 24 hours is not serious and critical levels are unlikely to occur. The birth weight, general condition and the age in days are other important factors, which should be taken into consideration.

1. **Exchange transfusion:** It is mainly indicated in severe hemolytic disease due to Rh incompatibility. The idea is to remove the excess bilirubin as well as the maternal antibodies responsible for hemolysis.
 - **Indications:** Exchange transfusion is indicated in the following conditions:
 - a. Cord bilirubin above 5 mg/dl or hemoglobin below 10 gm/dl.
 - b. Rapid rise of bilirubin level (more than 1 mg/hour).
 - c. Serum bilirubin level exceeding the critical level.
 - d. Clinical signs suggesting kernicterus at any serum bilirubin level.
 - **Blood used:** The blood used for exchange should be fresh, group O, Rh negative. The infant's blood group, Rh negative is an alternative.
 - **Procedure:** The procedure is carried out through an umbilical vein catheter, where alternating aspiration of 20 ml of infant blood and infusion of 20 ml of donor blood is made. The amount of blood used should equal the double volume of the infant blood ($2 \times 85 \text{ ml/kg}$). The whole procedure should be carried out over one hour.
 - **Follow-up:** After exchange transfusion, repeated measurements of serum bilirubin every 6-8 hours are important. Phototherapy is usually needed after the first exchange to keep serum bilirubin below the critical level. However, a second or even a third exchange may be indicated in severe cases with rapidly rising bilirubin level.
2. **Phototherapy:** Exposure of the jaundiced skin to fluorescent light is effective in lowering the unconjugated serum bilirubin level. Skin bilirubin absorbs light and unconjugated bilirubin is converted into unconjugated isomers that are excreted in bile and urine.
 - **Indications:** Phototherapy is mainly indicated in the following conditions:
 - a. Following exchange transfusion to avoid subsequent transfusions.
 - b. In premature infants with clinical jaundice to avoid critical levels.
 - c. In term infants with values near critical levels (above 15 mg/dl).Exaggerated physiological jaundice, hemolytic disease due to ABO incompatibility and cephalohematoma are the main indications.
 - **Procedure:** Phototherapy should be continuous (throughout the 24 hours) with frequent change of position to ensure maximal skin exposure. Eyes and may be genitalia should be covered to prevent the harmful effect of light on these organs. Initial response to therapy is usually attained after 12 hours of exposure where values 1-2 mg lower than the initial values are usually obtained.
 - **Follow-up:** Repeated measurements of serum bilirubin can be made every 12-24 hours. Phototherapy should be continued until serum bilirubin becomes unlikely to reach critical levels. Values below 12 mg/dl in term infants can be considered as a criterion to discontinue phototherapy.
 - **Side effects:** Phototherapy is generally safe. Loose stool, skin rash and hyperthermia may occur. Grayish brown discoloration (Bronze Baby syndrome) may occur in infants with mixed hyperbilirubinemia.

3. **Phenobarbital:** The use of phenobarbital (6 mg/kg/day) to enhance bilirubin conjugation and excretion is currently limited to rare conditions of persistent unconjugated hyperbilirubinemia as Crigglar Najjar syndrome or Gilbert disease.
4. **Specific treatment:** The cause of jaundice especially neonatal sepsis should be treated with parenteral antibiotic therapy. The factors that increase the risk of neurological damage as hypoxemia, shock and acidosis should be urgently corrected.

45 Chapter

Serious Neonatal Vomiting

Surgical emergencies

Tracheoesophageal fistula
Congenital intestinal obstruction
Acquired intestinal obstruction

Serious medical conditions

Serious infections
Increased intracranial pressure
Inborn errors of metabolism

Any normal neonate or infant may regurgitate or vomit once or even twice a day. This occasional vomiting should not be mistaken with the frequent or persistent vomiting which should be taken with concern.

Clinical evaluation of neonatal vomiting should include the general condition, onset and character of vomiting and the associated clinical manifestations. Causes can be then classified into 2 groups:

- a. **Vomiting in doing well baby:** In this group, vomiting is the only clinical manifestation and it is never bile stained. Otherwise, the baby looks well with good activity and suckling power. There is no fever, abdominal distension, disturbed consciousness, convulsions or respiratory distress. The main causes are amniotic gastritis, swallowed maternal blood, feeding disorders, cows milk protein intolerance, gastroesophageal reflux and congenital pyloric stenosis.
- b. **Vomiting in sick baby:** In this group, vomiting may be bile-stained and is usually associated with other significant clinical findings as poor suckling, fever, disturbed consciousness, convulsions or abdominal distension. The baby is sick and usually necessitates hospitalization. Vomiting is caused by either a surgical emergency or a serious medical condition. Surgical causes include tracheoesophageal fistula, congenital intestinal obstruction and acquired intestinal obstruction. Serious infections (pneumonia, septicemia, meningitis), increased intracranial pressure and inborn errors of metabolism are the main medical causes.

Laboratory evaluation is individualized and depends on the most likely clinical diagnosis.

Possible investigations of neonatal vomiting

Barium swallow or radio-opaque catheter into the stomach: Suspected tracheoesophageal fistula.
 Plain X-ray abdomen, erect position: Suspected intestinal obstruction.
 Cranial ultrasound: Suspected increased intracranial pressure.
 Sepsis screen: Suspected neonatal septicemia.
 Metabolic screen: Suspected inborn errors of metabolism.
 Barium esophagography under screen: Suspected gastroesophageal reflux.
 Barium meal: Suspected pyloric stenosis.

SURGICAL EMERGENCIES

1. **Tracheoesophageal fistula (TEF):** It should be suspected at birth when there is unusual drooling from the mouth or with inability to pass a catheter into the stomach. Vomiting occurs with the first feed in a characteristic way after one or two swallows there is vomiting, coughing, choking and cyanosis. The picture is repeated with every trial of feeding leading finally to aspiration pneumonia. Immediate radiological studies are essential. Radiological diagnosis is made by failure to pass a radio-opaque catheter into the stomach and the catheter is shown coiled in the upper esophageal pouch. There are 5 types of tracheoesophageal fistula (see Basic Pediatric Radiology). The most common type is atresia with lower fistula (85%) followed by atresia without fistula (10%). Other associated anomalies are common including the VATER syndrome (vertebral and vascular defects, tracheoesophageal fistula with esophageal atresia, renal dysplasia and renal defects).
2. **Congenital intestinal obstruction:** Vomiting usually starts in the first day or two in high obstruction and few days later in low obstruction. The vomiting is frequent, copious and bile-stained and is usually associated with abdominal distension and constipation. An urgent X-ray of the abdomen (erect position) is essential for diagnosis. In high obstruction (e.g. duodenal atresia), the double-bubble and double-fluid level can be demonstrated. In low obstruction (e.g. malrotation and volvulus), multiple fluid levels and marked abdominal distension are evident (see Basic Pediatric Radiology). The condition should be differentiated from acquired intestinal obstruction whether mechanical or functional. Intestinal perforation and pneumoperitoneum may occur in neglected cases.

Causes of congenital intestinal obstruction

High obstruction

Duodenal atresia
 Annular pancreas
 Congenital fibrous band of Ladd

Low obstruction

Jejunal or ileal atresia
 Malrotation and volvulus
 Intestinal duplication
 Meconium ileus
 Hirschsprung disease
 Imperforate anus

- In meconium ileus, there is no multiple fluid levels but the distended small bowel may be granular appearance or may show tiny bubbles mixed with meconium.

3. **Acquired intestinal obstruction:** *Functional obstruction* (paralytic ileus) is a common problem, which may occur with severe hyaline membrane disease, neonatal septicemia, meconium or mucous plugs and necrotizing enterocolitis. *Mechanical obstruction* may also occur as in intussusception, strangulated inguinal hernia, mesenteric thrombosis and necrotizing enterocolitis. In acquired obstruction, the onset of vomiting is usually not during the first few days. Necrotizing enterocolitis is a serious disease affecting mainly the sick prematures in neonatal intensive care units.

Predisposing factors include perinatal asphyxia, polycythemia, early feeding, hyperosmolar feeds and umbilical vessel catheterization. The disease starts with increasing gastric aspirates and vomiting which is usually bile-stained. Abdominal distension and bloody diarrhea quickly follow. Intestinal perforation and peritonitis are common complications. Septic and hypovolemic shock may also occur and the baby may collapse or die. Plain x-ray of the abdomen shows multiple fluid levels and may be intramural gas (pneumatosis intestinalis), which is characteristic. If perforation occurs, pneumoperitoneum can be demonstrated (see Basic Pediatric Radiology).

SERIOUS MEDICAL CONDITIONS

1. **Serious infections:** Septicemia, pneumonia and meningitis present in early stages with nonspecific manifestations as lethargy, poor suckling, vomiting, fever or hypothermia. The possibility should be considered in any baby who is not doing well and sepsis screen should be made (see neonatal sepsis).
2. **Increased intracranial pressure:** Vomiting with bulging fontanel and other neurological manifestations as disturbed consciousness or convulsions should suggest the condition. Hypoxic ischemic encephalopathy, intracranial hemorrhage and neonatal meningitis are the main causes. Cranial ultrasound and lumbar puncture are important for diagnosis (see neonatal convulsions).
3. **Inborn errors of metabolism:** The possibility should be considered in any sick newborn with unexplained vomiting. Exclusion of surgical emergencies and other serious medical conditions should be the first step. The baby is usually normal at birth and symptoms appear after a few days of milk intake. Organic acidemia and hyperammonemia are the main causes (see neonatal convulsions). Congenital adrenal hyperplasia should be considered in any newborn with severe vomiting leading to weight loss and dehydration. The possibility becomes great when serum electrolytes show severe hyponatremia and hyperkalemia. In females, virilized external genitalia is usually evident but in males, the genitalia is normal and the diagnosis is more difficult.



Section 11

Therapeutic Intervention

- Drug Therapy
- I.V. Fluid Therapy
- Transfusion Therapy
- Nutritional Therapy
- Oxygen Therapy
- Aerosol Therapy
- Chest Physiotherapy and Suctioning
- Mechanical Ventilatory Support
- Acute Peritoneal Dialysis

46

Chapter

Drug Therapy

Emergency Medications

Cardiovascular drugs
Respiratory drugs
Neurologic drugs
Metabolic drugs
Hematologic drugs
Antidotes

Parenteral anti-infective drugs

Parenteral antibiotics

Penicillins
Cephalosporins
Aminoglycosides
Carbapenems and other drugs

Parenteral antiviral drugs

Parenteral antifungal drugs

Drug therapy is an integral part in the management of critically sick children. The dosage, proper usage and available preparations of these drugs should be known to all doctors and nurses. As a rule, dosage should be calculated by 2 doctors to avoid accidental mistakes and nurses should be able to check dosage and notify doctors in case of suspicion.

The drugs used in critical care medicine can be broadly classified into emergency medications and parenteral anti-infective drugs.

EMERGENCY MEDICATIONS

Cardiovascular drugs

Resuscitation drugs

These drugs are used in cardiac arrest rhythms, not responding to assisted ventilation and cardiac compression, to restore normal cardiac rhythm.

- **Sodium bicarbonate: 1 mEq/kg, I.V.** Practical dosage is 1 ml/kg of the 8.4% solution or 2 ml/kg of the 5% solution. It is used to correct the associated metabolic acidosis. Available preparation are sodium bicarbonate 8.4 and 5%.
- **Adrenaline: 0.01 mg/kg, I.V. or intraosseous or endotracheal.** Practical dosage is 0.1 ml/kg of the diluted solution (1 ml + 9 ml saline). If it is not effective within 3-5 minutes, the second dose is 10 times the first dose (0.1 mg/kg of the undiluted solution) given I.V. intraosseous or endotracheal. The dose can be repeated every 3-5 minutes. Its resuscitative efforts are prolonged. Available preparation is adrenaline amp (1 mg/ml).

- **Lidocaine:** *1 mg/kg, I.V. or intraosseous or endotracheal.* It is used in ventricular fibrillation or pulseless ventricular tachycardia not responding to defibrillation (3 times) and adrenaline. Available preparation is Lidocaine or Zylocaine vial (1 gm/50 ml). See cardiopulmonary resuscitation.

Antiarrhythmic drugs

These drugs are used in serious life-threatening arrhythmias.

- **Atropine sulphate:** *0.01 mg/kg, I.V. or intraosseous or endotracheal.* It is used in severe bradycardia not responding to 100% oxygen. Available preparation is Atropine sulphate (1 mg/ml). Practical dosage is 0.1 ml/kg of the diluted solution (1 ml + 9 ml saline).
- **Isoproterenol:** *0.1 - 1.0 mcg/kg/minute, continuous I.V. infusion.* It is used in severe bradycardia not responding to atropine. Available preparation is Isuprel amp. (1 mg/5 ml). For dilution and infusion rate see shock.
- **Adenosine:** *50-250 mcg/kg, I.V. bolus.* It is the drug of choice in supraventricular tachycardia. The first dose (50 mcg/kg) can be followed by a second dose (150 mcg/kg) after 2 minutes and even a third dose (250 mcg/kg) after another 2 minutes. Available preparation is adenocor amp. (5 mg/2 ml).
- **Verapamil:** *50-100 mcg/kg, I.V. over 2 minutes.* It can be used in supraventricular tachycardia. Cardiac monitoring during injection is important because hypotension and asystole may occur. Available preparation is isoptin amp. (5 mg/2 ml).
- **Propranolol:** *100-200 mcg/kg, I.V.* It is used in supraventricular tachycardia. Cardiac monitoring is important because hypotension and asystole may occur. It is also used in hypercyanotic attacks of congenital cyanotic heart disease to relieve infundibular spasm. Available preparation is inderal amp. (1 mg/ml).
- **Lidocaine:** *1 mg/kg, slow, I.V.* It is the drug of choice for ventricular arrhythmias. Available preparation is lidocaine or xylocaine vial (1 gm/50 ml).
- **Phenytoin:** *3-5 mg/kg, I.V. over 5 minutes.* It is used as an alternative to lidocaine in ventricular arrhythmias. Available preparation is Epanutin amp. (250 mg/5 ml).

Inotropic drugs

These drugs are used to increase myocardial contractility. Digoxin is used in acute congestive heart failure but it is not suitable in cardiogenic shock because of the slow onset of action (digitalization) and narrow therapeutic range. Dopamine and dobutamine are suitable in cardiogenic shock because of the immediate effect and the dose-dependent response.

- **Digoxin:** *0.05 mg/kg (loading dose) and 0.01 mg/kg (maintenance dose).* The loading dose is divided into 3 doses, every 8 hours and the maintenance dose is divided into 2 doses every 12 hours. Available preparation is Digoxin Lanoxin amp. (0.5 mg/2 ml). The total digitalizing dose should not exceed the adult dose (1.5 mg).
- **Dopamine:** *2-20 mcg/kg/minute, continuous I.V. infusion.* Available preparation is intropin amp. (200 mg/5 ml). Low dose dopamine (0.5-4.0 mcg/kg/minute) is used in acute renal failure to increase renal blood flow (see shock and acute renal failure).

- **Dobutamine:** *2-20 mcg/kg/minute, continuous I.V. infusion.* Available preparation is Dobutrex or Dobuject vial (250 mg). It is used in cardiogenic shock and septic shock and can be used simultaneously with dopamine (see shock).
- **Adrenaline:** *0.05-1.0 mcg/kg/minute, continuous I.V. infusion.* Available preparation is Adrenaline amp. (1 mg/ml). It is used in extremely severe or desperate cases of cardiogenic shock. As it causes marked vasoconstriction and reduction of renal blood flow, a vasodilator drug (as nitroprusside) should be used simultaneously to counteract its undesirable effects (see shock).
- **Isoproterenol:** *0.05-2.0 mcg/kg/minute, continuous I.V. infusion.* Available preparation is Isuprel amp (1 mg/5 ml). It is only used when severe bradycardia is present and when pulmonary vasodilatation is required (see shock).

Afterload reducing agents

These vasodilator drugs are mainly used in cardiogenic shock not adequately responding to inotropic drug support (see shock).

- **Nitroprusside:** *0.5-10 mcg/kg/minute, continuous I.V. infusion.* Available preparation is Nipride vial (50 mg/2 ml). It is an arterial vasodilator more than venous vasodilator. As the drug is rapidly inactivated by light (photochemical degradation), the drip bottle and the tubing system should be covered with aluminium paper (included with the vial).
- **Nitroglycerin:** *1-20 mcg/kg/minute, continuous I.V. infusion.* Available preparation is Tridil amp. (50 mg/10 ml). It is a venodilator more than arterial dilator.
- **Amrinone:** *1-20 mcg/kg/minute, continuous I.V. infusion.* Available preparation is Inocor amp. (100 mg/20 ml). It is a new agent, which has both inotropic and afterload reducing effects.

Antihypertensive drugs

These drugs are used in treatment of systemic hypertensive crisis. Nifedipine or hydralazine are used in moderate cases and diazoxide or sodium nitroprusside are used in severe cases. Furosemide is also effective and can be used.

- **Nifedipine:** *0.2-0.5 mg/kg/dose, sublingual.* Available preparation is Epilat capsule (10 mg). The contents of the gelatin capsule are placed sublingually for immediate effect. The dose may be repeated every 30-60 minutes, when necessary.
- **Hydralazine:** *0.2-0.5 mg/kg, I.V.* Available preparation is Aprisoline or Hydralazine amp (20 mg/ml). It is effective in 30 minutes with duration of action for 3-6 hours.
- **Diazoxide:** *2-5 mg/kg, I. V.* Available preparation is Hyperstat vial (300 mg/20 ml). It is an immediately acting drug with duration of action for 3-6 hours.
- **Nitroprusside:** *0.5-5.0 mcg/kg/minute, continuous I.V. infusion.* Available preparation is Nipride vial (50 mg/2 ml). It is highly effective drug with immediate onset of action. It is an arterial vasodilator (see above).
- **Furosemide:** *2 mg/kg, I.V.* Available preparation is Lasix amp. (20 mg/2 ml). It is an effective drug which can be repeated after 4-6 hours, when necessary.

Respiratory Drugs

The bronchodilators are used in acute severe asthma to relieve bronchospasm.

- **Salbutamol inhalation:** It has the advantage of easy administration and rapid onset of action. In cooperative children above the age of 8 years, inhalation through the mouth is made with the commercially available inhalers (Ventolin inhaler, 100 mcg/metered inhalation). In young children, drug is given through nebulization where 0.25-0.5 ml of the solution is added to 2-3 ml saline (Ventolin nebulization solution, 5 mg/ml). See also aerosol therapy.
- **Ipratropium inhalation:** It can be used as inhaler or nebulization solution. Available preparations are (Atrovent inhaler, 20 mcg/metered inhalation and Atrovent pediatric nebulization solution, 250 mcg/2 ml).
- **Adrenaline:** *0.01 mg/kg, subcutaneously.* Practical dosage is 0.1 ml/kg of the diluted solution (1 ml +9 ml saline). Available preparation is adrenaline amp. (1 mg/ml). The dose can be repeated after 15-20 minutes, when necessary.
- **Theophylline:** *5 mg/kg, slow, I.V. every 6 hours.* It can also be given by continuous I.V. infusion where the calculated dose is given over 6 hours. Available preparations are Minophylline amp. (300 mg/2 ml) and Minophylline amp. (500 mg/5 ml).
- **I.V. corticosteroids:** Hydrocortisone (5-10 mg/kg, I.V., every 6 hours), methylprednisolone (1-2 mg/kg, I.V. every 6 hours) or dexamethazone (0.2 mg/kg, I.V. every 12 hours) can be used (see acute asthma).

Neurologic drugs

Anticonvulsants

- **Diazepam:** *0.3-0.5 mg/kg, I.V. over 3 minutes.* Available preparation is Valium or Stesolid or Neuril amp. (10 mg/2 ml). Practical dosage is 0.1 ml/kg. When I.V. line cannot be established, the calculated dose can be given rectally by a syringe and a flexible tube. The drug can also be given by constant I.V. infusion (see status epilepticus).
- **Phenobarbital:** *15-20 mg/kg, I.V. over 3 minutes.* Available preparation is Sominaletta amp. (40 mg/ ml). It is the drug of choice in neonatal convulsions and it is used in infants and children when diazepam is not effective. The dose can be repeated in refractory cases.
- **Phenytoin:** *15-20 mg/kg, I. V. over 5 minutes.* Available preparation is Epanutin amp. (250 mg/5 ml). Monitoring of the heart during injection is important as serious heart block may occur. It is used when diazepam and phenobarbital are not effective to control the ongoing convulsive fit.

When the above 3 drugs are not effective (refractory status epilepticus), the following serious drugs can be used, in ICU:

- **Paraldehyde:** *150-200 mg/kg, I.V. over 15 minutes.* The bolus dose is followed by I.V. infusion (20 mg/kg/hour). A 5% solution is made (2 ml paraldehyde (2 gm) +38 ml glucose 5%) and a glass bottle is used for infusion.

- **Lidocaine:** *1 mg/kg, slow I.V.* The bolus dose is followed by I.V. infusion (2 mg/kg/hour). Available preparation is Lidocaine or Xylocaine vial (1 gm/50 ml).
- **Thiopental:** *2-4 mg/kg, slow I.V.* The bolus dose is followed by I.V. infusion (2 mg/kg/hour). Available preparation is Intraval or thiopental vial (500 mg).
- **Pancuronium:** *0.1 mg/kg, I.V.* Available preparation is Pavulon amp. (4 mg/2 ml). Practical dosage is 0.5 ml/kg of the diluted solution (1 ml + 9 ml saline). It is used in refractory status epilepticus to induce muscle paralysis (electromechanical dissociation). Endotracheal intubation and mechanical ventilation are necessary. It is also used in mechanically ventilated patients who are fighting the ventilator (patient-ventilator asynchrony). The dose can be repeated every 2-3 hours.

Drugs to reduce the increased intracranial pressure

These drugs are used in comatose patients with manifestations of increased intracranial pressure. It is important to remember that head elevation 30° and mechanical hyperventilation are the most rapid methods for reduction of increased intracranial pressure.

- **Mannitol 20%:** *5-10 ml/kg, I.V. over 30 minutes.* The dose can be repeated every 6 hours but care should be taken to avoid hypervolemia and hyperosmolarity. Available preparation is Mannitol 20% solution.
- **Furosemide:** *2 mg/kg, I.V.* The dose can be repeated every 4-6 hours. It is less effective than mannitol and has a slower onset of action. It is advisable to use both drugs together to achieve rapid effect and to avoid high doses of mannitol. Available preparation is Lasix amp. (20 mg/2 ml).
- **Steroids:** These drugs are only useful in vasogenic brain edema around brain tumors, extravascular blood or surgically induced edema. Dexamethazone (0.25 mg/kg, I.V., every 6-12 hours) or methylprednisolone (1-2 mg/kg, I.V., every 6 hours) can be used.
- Lidocaine and Thiopental are highly effective, but serious drugs.

Strong sedatives

These drugs are used prior to several diagnostic procedures as catheterization, endoscopy, ECG, EEG and CT scanning. They are also used in mechanically ventilated children to allay anxiety and to overcome ventilator fighting by the patient.

- **Diazepam:** *0.1-0.2 mg/kg, I.V.* The dose can be repeated every 30-60 minutes when necessary. Available preparation is Valium or Stesolid or Neuril amp. (10 mg/2 ml).
- **Midazolam:** *0.1-0.2 mg/kg, I.V.* The loading dose may be followed by a constant infusion (50 mcg/kg/hour). It is a 3-5 times more potent than diazepam and it has the advantage of sedation without impairment of consciousness (conscious sedation). Available preparation is Dormicum amp. (5 mg/ml).

Narcotic analgesics

These drugs are used to relieve severe pain especially with serious injuries as multiple trauma, fractures and burn injuries.

- **Morphine:** *0.1 mg (100 mcg)/kg, I.V.* It can also be given as a constant infusion (0.1 mg/kg/hour). Duration of action is 3-4 hours. Overdosage produces respiratory depression, which can be reversed by naloxone. Available preparation is Morphine sulphate amp. (10 mg/ml).
- **Fentanyl:** *0.001 mg (1 mcg)/kg, I.V.* It can also be given as a constant infusion (1-2 mcg/kg/hour). It is a 100 times more potent than morphine. Duration of action is only 30-60 minutes. Available preparation is Fentanyl vial (0.1 mg/2 ml).

Metabolic drugs

These drugs are used in serious acute metabolic conditions. Laboratory confirmation of the diagnosis before therapy is important.

- **Sodium chloride 3%:** *5-10 ml/kg, I.V.* The rate of infusion should be as slow as 1 ml/minute. It is used to treat severe symptomatic hyponatremia with serum sodium below 120 mEq/litre. Each 1 ml/kg of this hypertonic saline solution will raise serum sodium level by about 1 mEq.
- **Sodium bicarbonate 5%:** *2-4 ml/kg, slow I.V.* It is used to treat acute severe metabolic acidosis with pH below 7.2 and bicarbonate below 10 mEq/litre. Each 1 ml/kg of this solution will raise the serum bicarbonate level by about 1 mEq. (see metabolic emergencies).
- **Calcium gluconate 10%:** *1 ml/kg, I.V. over 5-10 minutes.* Monitoring of the heart during injection is necessary and injection should be discontinued if bradycardia occurs. It is used to treat tetany or hypocalcemic convulsions. It is also used in hyperkalemia to counteract the effect of potassium on the heart.
- **Magnesium sulphate 10%:** *1-2 ml/kg, I.V. over 10-20 minutes.* It is used to treat hypomagnesemic convulsions or tetany.
- **Glucose 25%:** *1-2 ml/kg, I.V.* It is used to treat hypoglycemic convulsions with blood sugar level below 30 mg/dl.
- **Regular insulin:** *0.1 unit/kg/hour.* For details of therapy, see diabetic ketoacidosis.
- **Acetylsalicylic acid:** *10-15 mg/kg/dose, I.V.* Available preparation is Aspegic injectable (500 mg/5 ml). Practical dosage is 1 ml/kg of the diluted solution (1 ml + 9 ml saline). It is used to lower body temperature in case of hyperpyrexia (temperature above 41.0°C).

Hematologic drugs

These drugs are used in bleeding disorders.

- **Vitamin K1:** *5-10 mg, I.V.* Available preparation is Konakion amp (10 mg). It is used in hemorrhagic disease of the newborn, acute hepatic failure and DIC.
- **Heparin:** *50-100 unit/kg/dose, I.V. every 4 hours.* Available preparation is Heparin amp. (5000 unit/ml). Practical dosage is 0.1-0.2 ml/kg of the diluted solution (1 ml + 9 ml saline). It is only used in DIC associated with widespread cutaneous thrombosis as purpura fulminans.

Antidotes

These drugs are used in poisoning to counteract the effect of the poison.

- **Atropine:** *0.1 mg/kg, I.V.* The dose is repeated every 10-30 minutes until pupillary dilatation occurs. It is used in organic phosphorus poisoning. Available preparation is Atropine sulphate wnp. (1 mg/ml~).
- **Naloxone:** *0.01 mg/kg, I.V.* The dose is repeated every 2-3 minutes up to 3 doses. In case of poor response, the dose can be increased to 10 times the initial dose. It is used as a respiratory stimulant in respiratory depression due to opioid overdosage. Maternal narcotic analgesic drug administration is an important cause of CNS respiratory depression in the newborn. Available preparation is Narcan amp. (0.4 mg/ml).
- **Deferoxamine:** *10-15 mg/kg/hour, continuous I.V.* infusion. It is used in accidental iron poisoning with serum iron level above 350 mcg/dl. Available preparation is Desferal vial (500 mg). The contents of the vial are added to 100 ml saline and the infusion is made at a rate of 2-3 ml/kg/hour.
- **Methylene blue:** *1-2 mg/kg, I.V. over 10 minutes.* Practical dosage is 0.1-0.2 ml/kg of the 1% solution. It is used in methemoglobinemia due to nitrites or nitrates poisoning.
- **EDTA:** 250 mg/m²/dose, I.M. every 4 hours. It is used in lead poisoning and lead encephalopathy.

PARENTERAL ANTI-INFECTIVE DRUGS

These drugs are used in serious focal infections or fulminant sepsis. According to the therapeutic effect, they are classified into antibacterial, antiviral and antifungal drugs.

Antibacterial drugs

Penicillins

- **Penzylpenicillin:** *50.000-100.000 unit/kg/day, I.V.* The daily dose is divided into 4 doses. It is mainly used in staphylococcal pneumonia, staphylococcal meningitis and infective endocarditis. The dose can be increased to 300 mg/kg/day. Available preparation is Penicillin G vial (1.000.000 unit).
- **Ampicillin:** *100 mg/kg/day, I.V.* The daily dose is divided into 4 doses. It is mainly used in septicemia and meningitis. Available preparation is Ampicillin amp. (0.5 gm) and (1.0 gm).
- **Sultamicillin (ampicillin + sulbactam):** Same dosage of ampicillin. It has an extended activity against *Hemophylus influenza*, *E. coli*, *Klebsiella* and *Staphylococcus aureus*. Available preparation is Unasyn vial (375 mg) and (750 mg).
- **Amoxicillin:** *100 mg/kg/day, I.V.* The daily dose is divided into 3-4 doses. It is similar to ampicillin and it is used in the same indications. Available preparation is Amoxil vial (0.5 gm) and (1.0 gm).
- **Co-amoxiclav (amoxicillin + clavulanic acid):** Same dosage of amoxicillin. It has the same effect of sultamicillin. Available preparation is Augmentin vial (600 mg) and (1.2 gm).

- **Piperacillin:** 200 mg/kg/day, I.V. The daily dose is divided into 2-3 doses. It is used as an antipseudomonal drug. Available preparation is Pipril vial (1 gm), (2 gm) and (4gm).

Cephalosporins

- **Cefuroxime:** 50-100 mg/kg/day, I.V. The daily dose is divided into 2-3 doses. It is a broad spectrum second generation drug used in septicemia, meningitis and peritonitis. Available preparation is Zinnat vial (750 mg).
- **Cefotaxime:** 100-150 mg/kg/day, I.V. The daily dose is divided into 2-3 doses. It is used in septicemia, meningitis and peritonitis. Available preparation is claforan vial (0.25 gm), (0.5 gm) and (1.0 gm).
- **Ceftriaxone:** 100-150 mg/kg/day, I.V. The daily dose is given as a single injection. It is used in the same indications of cefotaxime. Available preparation is Rocephen vial (0.5 gm) and (1.0 gm).
- **Ceftazidime:** 100 mg/kg/day, I.V. The daily dose is divided into 2 doses. It is used in the same indications of cefotaxime and it is the drug of choice against pseudomonas infection. Available preparation is Fortum vial (0.25 gm), (0.5 gm) and (1.0 gm).

Aminoglycosides

These drugs are mainly used in neonatal sepsis, severe pneumonias, peritonitis and urinary tract infections.

- **Gentamicin:** 4-6 mg/kg/day, I.V. The daily dose is divided into 2 doses. Available preparation is Garamycin amp (20 mg), (40 mg) and (80 mg).
- **Tobramycin:** 5-7 mg/kg/day, I.V. The daily dose is divided into 2 doses. Available preparation is Nebcin vial (20 mg) and (80 mg).
- **Netilmicin:** 5-7 mg/kg/day, I.V. The daily dose is divided into 2 doses. Available preparation is Netromycin vial (50 mg) and (150 mg).
- **Amikacin:** 15 mg/kg/day, I.V. The daily dose is divided into 2 doses. Available preparation is Amikin vial (100 mg), (250 mg) and (500 mg).

Carbapenems

These broad-spectrum drugs are mainly used in empirical therapy of serious infections as septicemia, meningitis and peritonitis. They are expensive drugs.

- **Imipenem:** 60-100 mg/kg/day, I.V. The daily dose is divided into 3 doses. Available preparation is Tienem vial (500 mg in 50 ml solution).
- **Meropenem:** 60-100 mg/kg/day, I.V. The daily dose is divided into 3 doses. Available preparation is Meronem vial (500 mg).

Others drugs

- **Chloramphenicol:** 100 mg/kg/day, I.V. The daily dose is divided into 3-4 doses. It is mainly used in bacterial meningitis and salmonella infection. Available preparation is Miphenicol or Cidocetine vial (1.0 gm).

- **Aztreonam:** *90-120 mg/kg/day, I.V.* The daily dose is divided into 2-3 doses. Its activity is similar to that of third generation cephalosporins. Available preparation is Azactam vial (0.5 gm) and (1.0 gm).
- **Metronidazole:** *7.5 mg/kg/dose, I.V. Every 12 hours.* It is used in serious anaerobic infections as in neonatal necrotizing enterocolitis, peritonitis and following abdominal surgery. Available preparation is Flagyl infusion (500 mg/100 ml).
- **Clindamycin:** *20-40 mg/kg/day, I.V.* The daily dose is divided into 2-3 doses. It is used as an alternative to metronidazole in serious anaerobic infections. Available preparation is Dalacin C amp. (300 mg).
- **Vancomycin:** *40-60 mg/kg/day, I.V.* The daily dose is divided into 3-4 doses. It is the drug of choice for methicillin-resistant staphylococcus aureus. Available preparation is Vancocin vial (0.5 gm).

Antiviral drugs

- **Acyclovir:** *10 mg/kg/day, I.V.* The daily dose is given as an infusion over 1 hour. It is used in serious viral infections as neonatal herpes simplex, herpes encephalitis and severe generalized herpes infection. Available preparation is Zovirax amp (250 mg/5 ml).

Antifungal drugs

- **Fluconazole:** *3-6 mg/kg/day, I.V.* The daily dose can be given as a single dose or divided into 2 doses. It is used in serious systemic fungal infections as candidemia and candida infection of the lungs, peritoneum and endocardium. Available preparation is Diflucan I.V. infusion (100 mg/50 ml).

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Chapter

I.V. Fluid Therapy

Shock therapy (over maximum 1 hour)

20 ml/kg of Ringers lactate or saline may be repeated in severe case

Deficit therapy (over 8 hours)

40 ml/kg (mild dehydration)

80 ml/kg (moderate dehydration)

120 ml/kg (severe dehydration)

Solution used is a mixture of Kadalex and saline in a ratio of 1:1

Maintenance therapy (over 16 to 24 hours)

100 ml/kg/day (for first 10 Kg) +

50 ml/kg/day (for each kg from 11- 20 kg) +

20 ml/kg/day (for each kg above 20 kg)

Solution used is a mixture of Kadalex and saline in a ratio of 4:1

I.V. fluid therapy is a common therapeutic procedure in critical care medicine. According to the indication, I.V. fluid therapy can be divided into shock therapy, deficit therapy and maintenance therapy.

SHOCK THERAPY

Expansion of intravascular volume with volume expanders (preload augmentation) is initially indicated in all types of shock to improve tissue perfusion.

- **A crystalloid** as Ringer's lactate or saline is initially given I.V. in an amount of 20 ml/kg over 10-15 minutes. The dose can be repeated once or even twice in case of poor response (persistent poor perfusion and/or hypotension).
- **A colloid** as albumin or plasma may also be given in an amount of 10 ml/kg, I.V. over a period of 15 minutes. It has the advantage of maintaining oncotic pressure and less tendency to leak into the interstitial spaces.
- Failure of response to 50-70 ml/kg of volume expanders over the first 1-2 hours should suggest; (1) continued unrecognized fluid loss (capillary leak syndrome), (2) continued unrecognized blood loss (internal hemorrhage), (3) volume overload (renal failure or excess, I.V. fluids), (4) cardiogenic shock (impaired contractility), (5) obstructive shock (due to pneumothorax or cardiac tamponade) or (6) pulmonary hypertension (impaired right ventricular outflow). Obstructive shock should be initially excluded by chest X-ray (pneumothorax) and echocardiography (cardiac tamponade). When facilities for measurement of central venous pressure (CVP) are not available, the condition should be considered as a cardiogenic shock and inotropic

drug support (dopamine and/or dobutamine infusion) should be started to improve myocardial contractility.

- Following shock therapy with volume expanders, other aspects of cardiovascular support and treatment of the cause of shock should be considered (see shock).

DEFICIT THERAPY

Deficit I.V. fluid therapy is indicated in dehydration to replace the water and electrolyte losses. It should start immediately following the shock therapy with Ringer's lactate or saline and it should be given over 8 hours.

- **The amount** needed in deficit therapy depends on the degree of dehydration. It is 40 ml/kg in mild dehydration, 80 ml/kg in moderate dehydration and 120 ml/kg in severe dehydration. In patients with body weight above 10 kg, the amount equals the maintenance $\times 0.4$ in mild dehydration, maintenance $\times 0.8$ in moderate dehydration and maintenance $\times 1.2$ in severe dehydration.
- **The solution** used is a mixture of glucose 5% and normal saline in a ratio of 1:1 with addition of KCl 15% solution (1 ml for each 100 ml of the mixture). An alternative solution is Kadalex and saline in a ratio of 1:1 without addition of potassium chloride solution. Exceptions to this rule are:
 - a. *Hypernatremic dehydration*: The solution used is a mixture of glucose 5% and saline in a ratio of 1:1 with the addition of potassium chloride 15% (1 ml for each 100 ml of the mixture). The amount given should be reduced to 60-70% of the calculated amount (see metabolic emergencies and severe gastroenteritis).
 - b. *Diabetic ketoacidosis*: Therapy should start with saline until blood sugar level is below 300 mg/dl, then the solution is changed to glucose 5% and saline mixture in a ratio of 1:1 with the addition of KCl 15% solution (1 ml for each 100 ml of the mixture).
 - c. *Burns*: Ringer's lactate is the most commonly used I.V. fluid to provide the additional requirements. Parkland formula is used to calculate the deficit therapy (4 ml/kg \times percentage burn). For details of therapy, see serious injuries.
 - d. *Acute renal failure*: The deficit therapy should be given without the addition of potassium chloride solution until an adequate urine flow is obtained (see acute renal failure).

MAINTENANCE THERAPY

Maintenance I.V. fluid therapy is indicated in the following conditions; (1) following deficit therapy in dehydrated patients, (2) in critically sick patients as those with respiratory distress, acute congestive heart failure, shock, coma or acute hepatic failure. In these conditions, oral feeding is hazardous and leads to serious aspiration, (3) severe persistent vomiting to prevent fasting dehydration, (4) in the first few days of postoperative care where oral feeding is temporarily discontinued.

- **The amount** needed equals 100 ml/kg/day for the first 10 kg body weight. 50 ml/kg/day are added for each kg from 11-20 kg, and 20 ml/kg/day are added for each kg above 20 kg. Exceptions to these rules are:

- a. *The amount is increased* in the following conditions; (1) in neonates and young infants (150 ml/kg/day), (2) in febrile patients (add 10¼ for each degree above 37.8°C), (3) phototherapy (add 10%), (4) radiant warmer (add 20%), (5) continued losses as diarrhea (add 30%).
- b. *The amount is decreased* to 60-70% of the calculated requirements in patients with acute congestive heart failure, coma with increased intracranial pressure and in hypernatremic dehydration. In patients with anuria, only the insensible water losses are given.
- **The solution** used is a mixture of glucose 5% and normal saline in a ratio of 4:1 with addition of KCl 15% solution (1 ml for each 100 ml of the mixture). An alternative solution is Kadalex and saline in a ratio of 4:1 without addition of KCl solution. Exceptions to this rule are:
 - a. *Acute renal failure*: The maintenance therapy is given without addition of KCl solution until an adequate urine output is obtained.
 - b. *Acute hepatic failure*: An extra-amount of potassium is required to correct the commonly present hypokalemia. 1.75-2.0 ml of KCl solution 15% is added to each 100 ml of the mixture to make a potassium concentration of 35-40 mEq/litre.
 - c. *Comatose patients*: Glucose 10% solution can be used instead of the 5% solution to provide extra calories.
- **Duration**: The maintenance I.V. fluid therapy should be used for the least possible time (2-3 days) and oral feeding should be resumed as soon as the condition permits. If oral feeding cannot be resumed after 2-3 days as in those with prolonged coma or persistent severe respiratory distress, I.V. fluid therapy should be gradually replaced by nasogastric tube feeding. If tube feeding is not tolerated (as in intestinal malabsorption) or contraindicated (following major abdominal surgery), I.V. fluid therapy should be replaced by total parenteral nutrition (see nutritional therapy).

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Chapter

Transfusion Therapy

Whole blood transfusion

- 20 ml/kg in class II acute blood volume loss (20-25% blood loss)
- 30 ml/kg in class III acute blood volume loss (30-35% blood loss)
- 40 ml/kg in class IV acute blood volume loss (40-50% blood loss)
- 70 ml/kg (massive transfusion): In orthopedic and cardiopulmonary bypass surgery

Blood component transfusion

Red blood cells (Packed RBCs)	10-15 ml/kg
Granulocyte transfusion	1-2 x 10 ⁹ /kg neutrophils per transfusion
Platelet transfusion	1 unit/5 kg (or 10 ml/kg)
Cryoprecipitate antihemophilic factor	1 bag/5 kg (or 5 ml/kg)
Fresh frozen plasma (FFP)	10-15 ml/kg

Transfusion of blood or blood components is a lifesaving procedure in several acute life-threatening conditions. Hematological emergencies as acute blood loss, acute hemolytic anemia and DIC are the commonest indications.

WHOLE BLOOD TRANSFUSION

Whole blood transfusion is mainly indicated in hypovolemic shock due to acute blood volume loss, it aims to restore blood volume and to improve oxygen-carrying capacity.

- **Initial therapy:** Until the blood becomes available for transfusion (within 15-45 minutes), patients with hypovolemic shock due to blood loss should receive 100% oxygen (to correct tissue hypoxia) and volume expanders as Ringer's lactate in an amount of 20 ml/kg over 5-10 minutes to restore blood volume, and it can be repeated as needed.
- **Blood used:** In emergency situation of severe hypovolemic shock not adequately responding to Ringer's lactate, uncross-matched group O, Rh negative blood or uncross-matched type-specific ABO blood can be used to save time. In less urgent situation, a full cross-matched type-specific ABO blood should be used.
- **Volume:** The volume of blood needed depends on the estimated acute blood volume loss. It is 20 ml/kg in class II, 30 ml/kg in class III and 40 ml/kg in class IV. Massive transfusion is defined as a replacement of at least one blood volume of the patient (i.e. 70-75 ml/kg). It is indicated in massive trauma, orthopedic surgery, cardiopulmonary bypass surgery and extracorporeal membrane oxygenation.

- **Rate of infusion:** In emergency situations, infusion should be given as fast as patient can tolerate. In less urgent situations, infusion can be given within 1-2 hours.
- **Hazards:** Close observation throughout the transfusion period is essential. Temperature, HR and RR should be frequently monitored. Febrile or allergic reactions may occasionally occur and circulatory overload may occur in rapid or massive infusion.

BLOOD COMPONENT TRANSFUSION

Transfusion of blood components is indicated in symptomatic deficiencies of red cells, white cells, platelets or coagulation factors.

Red blood cell transfusion

Urgent red blood cell transfusion (packed RBCs) is indicated in symptomatic acute hemolytic anemia (intense pallor with manifestations of acute hypoxia as tachycardia and tachypnea). In severe cases, altered consciousness occurs due to hypoxic anemic encephalopathy.

- **Initial therapy:** Until the blood becomes available for transfusion, patients with acute hemolytic anemia should receive 100% oxygen to correct hypoxia. Volume expansion with Ringer's lactate is not required because acute hemolysis is not associated with hypovolemia.
- **Blood used:** In emergency situation of severe acute hemolysis, uncross-matched group O, Rh negative or uncross-matched type-specific ABO packed red cells can be used. In less urgent situation, a full cross-matched type-specific packed RBCs should be used. In patients who need repeated transfusions, as those with thalassemias, washed RBCs (leukocytes removed) are preferable to avoid febrile reactions.
- **Volume:** The volume of packed cells needed depends on the severity of acute hemolysis. Generally, 10-15 ml/kg of packed cells is initially sufficient. It is important to know that each 4 ml/kg of packed cells raises the hemoglobin by 1 gm/dl.
- **Rate of infusion:** In emergency situation, transfusion should be given as fast as patient can tolerate. In less urgent situations, transfusion can be given within 1-2 hours.
- **Hazards:** Febrile reactions and/or allergic reactions may occasionally occur; therefore, close observation throughout the transfusion period is essential.

Granulocyte transfusion

Transfusion of granulocytes is mainly indicated in neutropenia with fulminant bacterial or fungal infection not responding to appropriate antimicrobial therapy. Leukocyte dysfunction with fulminant bacterial or fungal infection is also an indication of granulocyte transfusion.

- Fresh leukapheresis cells should be used.

- In neonates and infants weighing less than 10 kg, the cells required for transfusion equal $1-2 \times 10^9/\text{kg}$. Larger infants and children should receive a total dose of 1×10^9 neutrophils per transfusion.
- The rate of infusion is one leukapheresis unit over 2-4 hours.
- Close observation is important as febrile or allergic reactions may occur.

Platelet transfusion

Transfusion of platelet concentrates is mainly indicated in severe thrombocytopenia with platelet count below 20.000 especially when associated with active bleeding. DIC and consumptive thrombocytopenia due to fulminant sepsis are the commonest indications. It aims to raise the platelet count above 50.000 to improve the hemostatic mechanism.

- The volume of transfusion is one unit/5 kg (or 10 ml/kg).
- The rate of infusion is one unit every 10 minutes. Platelet packs obtained by pheresis requires longer transfusion time.
- Close observation is important as febrile or allergic reaction may occur.

Cryoprecipitate transfusion

Cryoprecipitate is a source of factor VIII (antihemophilic globulin) and fibrinogen. Its transfusion is indicated as a replacement therapy in DIC and in bleeding episodes of hemophilia A. It aims to raise factor VIII level above 50% to improve the hemostatic mechanism.

- The volume of transfusion is one bag/5 kg (or 5 ml/kg), every 12 hours.
- The rate of infusion is about 10 ml/minute.
- Allergic or febrile reactions do not occur.

Fresh frozen plasma (FFP) transfusion

Transfusion of fresh frozen plasma is mainly indicated in coagulation defects as DIC and acute hepatic failure. It may also be used in bleeding episodes of hemophilia when cryoprecipitate is not available. The aim of therapy is to provide labile and non-labile plasma factors.

- The used plasma must be ABO-compatible.
- The volume of transfusion is 10-15 ml/kg and may be repeated every 12 hours.
- The rate of infusion is about 0.5 ml/kg/minute.
- Allergic reactions or infection (hepatitis, cytomegalovirus) may occur.

EXCHANGE TRANSFUSION

Exchange transfusion is a commonly used therapeutic procedure in neonatal emergencies. Severe Rh incompatibility and severe neonatal sepsis are the main indications. Uncross-matched group O Rh negative or cross-matched type-specific ABO blood can be used. The amount of blood used should equal the double blood volume of the infant ($2 \times 85 \text{ ml/kg}$). The whole procedure should be carried out over 1 hour (see early-onset neonatal jaundice).

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Chapter

Nutritional Therapy

Nasogastric tube feeding (NGTF)

- 150 ml/kg/day of humanized formula (in neonates and young infants)
- 120 ml/kg/day of humanized formula and weaning foods (in weaned infants)
- 100 ml/kg/day of blenderized formula or ready-made formula (in children)

Total parenteral nutrition (TPN)

- 30 ml/kg/day of mixture 1 (Vamin + Ped-el)
- 30 ml/kg/day of mixture 2 (Intralipid 10% + Vitalipid)
- 60-90 ml/kg/day of mixture 3 (Glucose 10% + Solu-vit)

Nutritional support of critically sick children is important for metabolic maintenance and tissue repair. During the first 24-48 hours of acute critical illness, oral feeding is hazardous and I.V. fluid therapy is usually given to provide water and electrolyte requirements. If oral feeding cannot be resumed after the first day or two of management, I.V. fluid therapy should be gradually replaced by nasogastric tube feeding. When nasogastric tube feeding is not tolerated or contraindicated, total parenteral nutrition should be considered.

NASOGASTRIC TUBE FEEDING

One of the golden rules in therapy is "If the gastrointestinal tract is intact, use it". For economic and physiological reasons, gastrointestinal feeding is the method of choice.

- **Indications:** In critical care medicine, nasogastric tube feeding is mainly indicated in comatose patients, in those with severe bulbar paralysis and in those with persistent respiratory distress. Oral feeding in these conditions is hazardous and can lead to serious aspiration.
- **Formulas and foods given:** In neonates and young infants, a humanized formula can be used. In weaned infants, humanized formula and weaning foods (cereals, vegetable soup, fruits) can be given. In children, a blenderized formula (home made or hospital made) can be used and it has the advantage of being unexpensive. Commercial ready-made formulas are also available and can be used. Ensure powder is a ready-made balanced diet. 5 scoops of the powder are added to 200 ml water to prepare 250 ml feed (each 1 ml contains 1 kcal).
- **Amount per day:** In neonates and young infants, 150 ml/kg/day of a humanized formula is given and it can be divided into 6-8 feeds. In weaned infants, 120 ml/kg/day of humanized milk and weaning foods can be given divided into 6 feeds. In children, 100 ml/kg/day of blenderized or ready made formula can be

given divided into 4-5 feeds. It is important to start with a small volume and a diluted formula, then the amount and strength are increased gradually over few days.

Suggested schedule for gradual introduction of tube feeding

Day	I.V. fluid therapy	Nasogastric tube feeding
Day 1	75% of maintenance	25% (1/2 strength)
Day 2	50% of maintenance	50% (3/4 strength)
Day 3	25% of maintenance	75% (full strength)
Day 4	Keep vein open	100% (full strength)

- **Technique:** A polyethylene nasogastric tube is inserted through one nostril into the stomach. A tube size of 5 or 6 French is used in infants and size 8 French in children. The calculated feed is either given by an infusion pump or allowed to advance by gravity. Alternatively, a big syringe (50 ml) can be used and a slow injection through the nasogastric tube is made. In young infants and in those who cannot tolerate the intermittent feeding, continuous tube feeding can be made where the calculated amount per day is infused continuously throughout the 24 hours.
- **Evaluation of tolerance:** The tolerance to feeding is evaluated on the basis of gastric residuals before the next feed, stool character and presence of vomiting, diarrhea or abdominal distention. Problems that may arise include:
 - a. **Tube obstruction:** The tube can be obstructed by thick formulas or medications. Irrigation after feeding with water and saline is important to prevent obstruction. The tube should be replaced by a new one every 3-4 days.
 - b. **Gastric retention:** Excess gastric residuals may occur due to high caloric value or high fat content. An antiemetic drug with gastrokinetic activity as metoclopramide or domperidone can be given rectally and a more diluted formula should be used.
 - c. **Diarrhea or abdominal cramps** may occur due to thick hypertonic formula, medications given through the tube or bacterial contamination of the formula or the used set. A more diluted formula should be used and the set should be changed. Persistence of vomiting and/or diarrhea after these measures necessitates discontinuation of tube feeding and total parenteral nutrition should be considered.
- **Duration and termination:** Tube feeding can be continued as long as several weeks or months. Termination of tube feeding should be gradual with the concomitant gradual increase in oral feeding. Daily tube feeding and oral feeding should be recorded to ensure that the total daily intake is adequate.

TOTAL PARENTERAL NUTRITION

Parenteral nutrition through the I.V. route is a potentially serious procedure, which should be only used when it is absolutely necessary and when perfect cooperation between doctors, nurses and laboratory is available.

- **Indications:** Total parenteral nutrition is only indicated when oral and nasogastric feeding are not tolerated and when the expected time for gastrointestinal recovery is more than 7-10 days. The main indications are severe prematurity, necrotizing enterocolitis, severe protracted diarrhea and major intestinal surgeries as massive resection. It may also be used in acute hepatic failure with significant gastrointestinal hemorrhage.
- **Solutions used:** Six solutions are required to provide carbohydrates (glucose 10070), fats (Intralipid 10%), proteins (Vamin), electrolytes and trace elements (Fed-el), fat soluble vitamins (Vitalipid infant) and water soluble vitamins (Soluvit).

Nutritional content and daily requirements of solutions used in TPN

Solution	Nutritional content	Daily requirements
Glucose 10%	100 gm glucose/litre	60-90 ml/kg/day
Intralipid 10%	100 gm fats/litre	30 ml/kg/day
Vamin	10 gm proteins/litre	30 ml/kg/day
Ped-el	Electrolytes, trace elements	4 ml/kg/day
Vitalipid	Vitamins A, D, KI	1 ml/kg/day (maximum 4 ml)
Solu-vit	Vitamin B, C	0.5 ml/kg/day

- Each 60 ml/kg of glucose 10% provides 6 gm/kg of glucose.
- Each 30 ml/kg of Intralipid 10% provides 3 gm/kg of fats.
- Each 30 ml/kg of Vamin provides 2.1 gm/kg of proteins (as amino acids).
- **Amount per day:** Three mixtures of solutions are made:
 - *Mixture 1:* Vamin (30 ml/kg/day) + Ped-el (4 ml/kg/day). This amount will provide 2.1 gm/kg of proteins, and the daily requirements of electrolytes and trace elements. The total daily dose should not exceed the adult dose (1000 ml).
 - *Mixture 2:* Intralipid 10% (30 ml/kg/day) + vitalipid (1 ml/kg/day, maximum 4 ml). This amount will provide 3 gm/kg of lipids and the daily requirements of fat-soluble vitamins and phosphorus. The total daily dose should not exceed adult dose (1000 ml).
 - *Mixture 3:* Glucose 10% (60-90 ml/kg/day) + Solu-vit (0.5 ml/kg/day). The amount of glucose 10% is 90 ml/kg/day in neonates and young infants, and 60 ml/kg/day in older infants and children.

It is important to note that the calculated full dosage of Vamin and Intralipid should be reached gradually over several days, and during these days, the amount of glucose 10% is increased to compensate for the decreased total amount.

Suggested schedule for gradual introduction of TPN in children

Day	Vamin	Intralipid 10%	Glucose 10%
Day 1	10 ml/kg/day	10 ml/kg/day	100 ml/kg/day
Day 2	15 ml/kg/day	15 ml/kg/day	90 ml/kg/day
Day 3	20 ml/kg/day	20 ml/kg/day	80 ml/kg/day
Day 4	25 ml/kg/day	25 ml/kg/day	70 ml/kg/day
Day 5	30 ml/kg/day	30 ml/kg/day	60 ml/kg/day

- **Technique:** Two I.V. lines are needed for infusion.
 - *Line 1:* It is used for Vamin and Intralipid infusion. There are 2 methods of infusion the sequential and the simultaneous methods. In the sequential method, Vamin is infused over 8 hours followed by Intralipid over the next 8 hours. In the simultaneous method, both Vamin and intralipid are infused simultaneously through separate infusion sets connected by a Y-shaped tap. No drugs should be injected through this line.
 - *Line 2:* It is used for glucose 10% and solu-vit mixture. The infusion is made throughout the 24 hours. Drugs can be injected through this line.

Alternatively, TPN may also be given through a central venous line especially when high concentrations are used.
- **Precautions and monitoring:** Certain precautions are important to minimize complications; (1) the calculated full dosage of Vamin and Intralipid should be reached gradually over several days (see above), (2) the solutions used and the I.V. tubing system should be changed every 24 hours to eliminate the risk of contamination, (3) the I.V. catheters should be checked frequently and should be changed to other veins in case of thrombophlebitis, (4) body weight and complete fluid balance (intake and output) should be recorded daily, (5) periodic laboratory investigations are essential. Serum electrolytes, blood sugar and plasma turbidity are checked every 2 days. If the plasma is milky or markedly opalescent, the intralipid infusion should be discontinued. Osmolarity, renal function (urea, creatinine) and liver function (bilirubin, transferases) should be checked every 4-5 days. After the first week of therapy, investigations can be only made once a week.
- **Risks and complications:** Several complications may arise with TPN:
 - a. *Infections:* Serious infections may occur from a local contamination or contaminated infusions. Vigorous antibiotic therapy, guided by blood culture, should be given.
 - b. *Hyperglycemia and hyperosmolarity:* This may occur due to a high glucose load. When blood sugar exceeds 300 mg/dl, regular insulin can be used in a dose of 1 unit for each 100 ml glucose 10%.
 - c. *Fever and acute chills:* This may occur during the first 12 hours of Intralipid infusion. Gastrointestinal bleeding may rarely occur with Intralipid infusion.
 - d. *Liver dysfunction:* Rising transferases may occur due to high protein load especially during the first week, but this usually subsides with continuation of therapy. With persistent elevation, Vamin infusion should be reduced. Conjugated hyperbilirubinemia may also occur with Intralipid infusion and necessitates reduction of dosage or discontinuation of Intralipid infusion.
 - e. *Deficiencies of trace elements:* It may occur with prolonged TPN.
- **Termination:** Once the oral or the nasogastric tube feeding becomes possible, TPN should be gradually discontinued over 2-4 days with the concomitant increase in oral intake.

Partial parenteral nutrition

In areas where facilities for TPN are not available, partial parenteral nutrition can be made and can provide a satisfactory support for up to 2 weeks. A maintenance solution of glucose 10% and saline is made in a ratio of 4:1. For each 100 ml of this solution, 1 ml of potassium chloride 15%, 2 ml of calcium gluconate 10% and 1 ml of magnesium sulphate 10% are added. Vamin is also used through a separate line in an amount of 30 ml/kg/day. Water-soluble vitamins (Parenterovit) may be added to Vamin solution.

Suggested schedule for partial parenteral nutrition

Day	Maintenance solution	Vamin solution
Day 1	110 ml/kg/day	10 ml/kg/day
Day 2	100 ml/kg/day	20 ml/kg/day
Day 3	90 ml/kg/day	30 ml/kg/day

- Intralipid infusion may also be added in a dose of 10-30 ml/kg/day with the concomitant reduction in the amount of maintenance solution.

50 Chapter

Oxygen Therapy

Indications

Arterial hypoxemia: Pneumonia, bronchiolitis, acute asthma, pulmonary edema
Acute severe anemia, shock states, acute brain insult

Methods of administration

High flow equipment: Incubators, head boxes, venturi face masks
Low flow equipment: Nasal cannulae, simple face masks

Dosage or concentration

100% oxygen with cyanosis, severe hemolysis, severe shock states
40-70% oxygen: Arterial hypoxemia, acute brain insult

Evaluation of response

Good response: Arterial oxygen saturation above 90% and PaO_2 above 90 mm Hg
Poor response: Saturation below 85% and PaO_2 below 60 mm Hg with 70% oxygen

Assessment of severity of lung pathology

Arterial/alveolar oxygen ratio ($\text{PaO}_2/\text{PAO}_2$): Normally, it is 0.8-0.9
Arterial/inspired oxygen ratio ($\text{PaO}_2/\text{FIO}_2$): Normally, it is 400-450

Oxygen is a drug. It has its own indications, methods of administration, dosage, duration of therapy and complications.

TISSUE OXYGENATION (PHYSIOLOGIC CONSIDERATION)

Oxygen is the most essential element for life and breathing in oxygen-free atmosphere is fatal in 4 minutes. The ultimate purpose of oxygenation in the lungs and oxygen transport in the blood is to provide oxygen to all body tissues to allow aerobic metabolism. The energy delivered through the aerobic metabolism is 20 times the energy of anaerobic metabolism. The brain metabolism is totally aerobic and this explains the rapid brain death in cardiopulmonary arrest. The process of tissue oxygenation depends on 3 successive steps:

Oxygenation in the lungs

The process of oxygenation is a process of "pressure difference". The oxygen moves from the high pressure environment to that of low pressure, i.e. oxygen moves from the atmosphere to the alveoli, arterial blood and tissues because the pressure of oxygen in atmosphere is higher than that in the alveoli, arterial blood and tissues.

- **Pressure of inspired oxygen (PIO₂):** It is the pressure of oxygen in atmosphere and the pressure responsible for oxygenation. This pressure depends on; (1) concentration of oxygen in the atmosphere, (2) barometric pressure, (3) water vapor pressure. The normal concentration of oxygen in air is 21%. In other words, the fraction of inspired oxygen (FIO₂) in air is 0.21. The normal barometric pressure (Bp) is 760 mm Hg and the normal water vapor pressure (H₂O_p) is 48 mm Hg.

Pressure of inspired oxygen is calculated from the following equation:

$$\begin{aligned}\text{PIO}_2 &= \text{FIO}_2 (\text{Bp} - \text{H}_2\text{Op}) \\ &= 0.21 (760 - 48) = 150 \text{ mm Hg}\end{aligned}$$

This is the pressure of inspired oxygen while breathing atmospheric oxygen (FIO₂ = 0.21) at sea level (Bp = 760 mm Hg).

- With oxygen therapy, PIO₂ increases because of increased FIO₂.
- In high altitude, PIO₂ decreases because of decreased barometric pressure.
- Below sea level, PIO₂ increases because of the increased barometric pressure.
- **Pressure of alveolar oxygen (PAO₂):** It is the pressure of oxygen inside the alveoli and it nearly equals the difference between the inspired oxygen pressure and the pressure of alveolar CO₂. As pressure of arterial CO₂ is almost the same as that of alveolar CO₂, pressure of alveolar oxygen can be calculated from the following equation

$$\begin{aligned}\text{PAO}_2 &= \text{PIO}_2 - (\text{PaCO}_2/\text{R}) \\ &= \text{FIO}_2 (\text{Bp} - \text{H}_2\text{Op}) - \text{PaCO}_2/\text{R} \\ &= 0.21 (760 - 48) - 40/0.8 \\ &= 150 - 50 = 100 \text{ mm Hg}\end{aligned}$$

This is the pressure of oxygen in alveoli while breathing atmospheric oxygen (FIO₂ = 0.21) at sea level (Bp = 760 mm Hg). With oxygen therapy, this pressure increases because of the increased FIO₂.

- **Pressure of arterial oxygen (PaO₂):** It is slightly lower than the pressure of alveolar oxygen and in normal condition it equals 90-95 mm Hg. The alveolar-arterial PO₂ difference (AaDO₂) equals 5-10 mm Hg and it is caused by normal physiological shunting, i.e. some alveoli are ventilated without being perfused (imperfect matching of ventilation to perfusion).

Oxygen transport in blood

Oxygen in the blood is present in two forms: (1) 3% of oxygen is physically dissolved in blood. This small part is responsible for arterial oxygen pressure (PaO₂) and it affects hemoglobin saturation with oxygen, (2) 97% of oxygen in the blood is chemically combined with hemoglobin. This part is responsible for Hb saturation and it affects oxygen delivery to tissues.

Oxygen in Blood

Dissolved Oxygen

- 3 %
- Responsible for PaO₂
- Affects Hb Saturation with Oxygen

Combined to hemoglobin

- 97 %
- Responsible for Hb saturation
- Affects Oxygen Delivery to tissues

- Oxygen transport in blood is evaluated by oxygen saturation and oxygen content.
- **Oxygen saturation:** The percentage of hemoglobin saturation with oxygen depends on the oxygen pressure and the relationship can be demonstrated by the “oxyhemoglobin dissociation curve” which is sigmoidal in shape, i.e. the upper part of the curve is flat and the lower part is steep.

Oxygen saturation at different oxygen pressures

Oxygen pressure (mm Hg)	100	90	80	70	60	50	40	30
Oxygen saturation (%)	97	96	95	93	90	85	75	55

- At higher levels of oxygen pressure (above 50-60 mm Hg), the curve is flattened and any increase in oxygen pressure produces only a little increase in saturation of oxygen. At the lung level, where oxygen pressure is high (PAO₂ 100 mm Hg), hemoglobin carries oxygen and the percentage saturation of hemoglobin with oxygen becomes 97%.
- At low levels of oxygen pressure (below 50 mm Hg), the curve is steep and small changes in oxygen pressure result in large changes of hemoglobin saturation. At the tissue level, where oxygen pressure is low (10-40 mm Hg), hemoglobin releases oxygen to tissues and the percentage saturation of hemoglobin with oxygen becomes 75%.
- **Oxygen content:** The amount of carried oxygen in the blood depends on oxygen saturation and hemoglobin level. As each 1 gm of hemoglobin carries 1.34 ml of oxygen, so, oxygen content can be calculated by the following formula:

$$\begin{aligned}\text{Oxygen content} &= \text{oxygen saturation (\%)} \times \text{hemoglobin (grams)} \times 1.4 \\ &= \text{SaO}_2 \times \text{Hb} \times 1.34\end{aligned}$$

Oxygen transport in the blood

- **Oxygen Saturation (SaO₂)**
 - It is the % of Oxyhemoglobin to total hemoglobin.
 - It depends on oxygen pressure (PO₂).
 - Normally, it is above 95 % (At Arterial Level) and around 75 % (at Venous Level).
- **Oxygen Content**
 - It depends on oxygen saturation and hemoglobin level.
 - As each 1 gm hemoglobin carries 1.34 ml oxygen
So, Oxygen Content = SaO₂ (%) x Hb (grams) x 1.34.

Oxygen delivery to tissues

Oxygen delivery to all body tissues depends on the tissue perfusion, which is directly related to the cardiac output and the **perfusion pressure (MAP–CVP)**. In shock states, hypoperfusion of tissues occurs and results in oxygen and substrate deficiency.

INDICATIONS

The main indication of oxygen therapy is arterial hypoxemia. Other indications of oxygen therapy include severe acute anemia (acute blood loss, acute hemolysis) and

shock states (hypovolemic, septic, cardiogenic, etc.). Oxygen is also important in acute brain insult (convulsions, coma, increased intracranial pressure). It is also important to remember that oxygen is the antidote in carbon monoxide poisoning.

Pathophysiological indications of oxygen therapy

1. Decreased environmental oxygen

Inhalation of nonphysiological gas mixture (inhalation injury in flame burns).

2. Impaired oxygenation in the lungs

Impaired alveolar ventilation

Severe airway obstruction (upper or lower).

Severe lung pathology (pneumonia, pulmonary oedema, aspiration etc.).

Severe respiratory weakness (CNS depression, respiratory paralysis).

Impaired alveolar perfusion (Abnormal pulmonary blood flow)

Persistent fetal circulation.

Acute pulmonary hypertension.

Acute pulmonary infundibular spasm (cyanotic spells).

Ventilation-perfusion mismatch (intrapulmonary shunt).

3. Impaired oxygen transport in blood (decreased oxygen-carrying capacity, i.e. low Hb)

Acute blood loss.

Acute hemolytic anemia.

4. Impaired oxygen delivery to tissues (Poor tissue perfusion)

Shock states.

METHODS OF ADMINISTRATION

The oxygen delivery system consists of the following:

- a. **Oxygen source:** Either oxygen cylinder or a central piping system with wall oxygen outlets. Wall oxygen is usually used in ICUs.
- b. **Oxygen flowmeter:** When oxygen cylinder is used, a “gas regulator” is mounted to act as a pressure regulator and flowmeter as well. When wall oxygen is used, an “oxygen flowmeter” is attached to the wall outlet to regulate the flow in litres/minute, i.e. 4 litres/minute. It usually has an adjustable control with “float-type” flow indicator.
- c. **Oxygen humidifier:** It is used to humidify the dry oxygen. The most commonly used type is the “bubbler humidifier” where the oxygen flows under water. When wall oxygen is used, the flowmeter and the humidifier are usually present as “one set”.
- d. **Oxygen delivery equipment:** It is the method by which the oxygen is given to the patient. There are several delivery equipment, which are suitable for different purposes.
- e. **Oxygen analyzer:** It measures the oxygen concentration in the oxygen-enriched atmosphere especially with head boxes and inside incubators.

Oxygen delivery equipment

Incubators

Only suitable for neonates and young infants.
Oxygen concentration inside usually does not exceed 40-50%.
Oxygen concentration can be measured by an oxygen analyzer.

Hoods or head boxes

Suitable for neonates, infants and may be young children (different sizes).
Oxygen concentration inside can be increased up to almost 100%.
Oxygen concentration can be measured by an oxygen analyzer.

Venturi face mask

Suitable for all age.
Deliver precise oxygen concentration (24%, 30%, 35%, 40%, 50%).
Oxygen concentration cannot be measured but can be known by the flow rate.

Simple face masks

Suitable for all ages.
Oxygen concentration is usually between 35-55% at flow rates of 6-10 litres/minute.
Oxygen concentration cannot be measured or precisely known.

Tight nonrebreathing face mask

Suitable when 100% oxygen is required (cyanosis, preintubation).
Attached to a reservoir bag with one-way valve to allow flow from bag to mask.
Exhaled gases are eliminated through another one-way valve on the face mask.

Nasal cannulae (nasal prongs)

Suitable for all ages.
Oxygen concentration is usually between 24-50% at flow rates of 1-6 litres/minute.
Oxygen concentration cannot be measured or even precisely known.

- 100% oxygen can also be given through manual ventilation with bag and mask or bag and tube attached to 100% oxygen source. Ventilators are also capable of providing oxygen from 21-100%.

DOSAGE OR CONCENTRATION

- In emergency situations as acute cyanosis, severe acute hemolysis, shock states and carbon monoxide poisoning, 100% oxygen should be immediately given by a tight nonrebreathing face mask or by assisted ventilation with the bag and mask attached to 100% oxygen.
- In less urgent situations as in those with respiratory distress and arterial hypoxemia, treatment usually starts with an oxygen concentration between 40-60%. The method used for oxygen delivery depends on (1) patient age, (2) patient comfort, (3) desired oxygen concentration, (4) need to measure the inspired oxygen concentration. Head boxes are the most suitable when a concentration above 50% is required and measurement of oxygen concentration is needed. Venturi masks are also reliable to provide precise concentrations ranging between 24-50%. Simple face masks or nasal cannulae can be used in less critical conditions when measurement of oxygen concentration is not required.
- Once oxygen is indicated, it should be given continuously. Interrupted oxygen therapy is physiologically harmful especially to sick infants and children.

- Dosage of oxygen can be changed (increased or decreased) according to the response. Changes in dosage are usually made by increments or decrements of 10% per time. Evaluation of response with every change is important.
- Oxygen therapy should be used for the least possible time. The actual duration depends on the causative disease. It may be only for few hours (as in acute allergic asthma), for several days (as in pneumonia and bronchiolitis) or several weeks (as in bronchopulmonary dysplasia).
- Oxygen should be withdrawn gradually. With oxygen concentrations above 40%, decrements of 10% per time are appropriate (from 60% to 50% to 40%). With concentration below 40%, decrements should be of 5% per time (40% to 35% to 30% to 24% then discontinue).

EVALUATION OF RESPONSE

Response to oxygen therapy can be evaluated clinically and in laboratory. Measurements of arterial oxygen saturation (SaO_2) and arterial oxygen pressure (PaO_2) are the most reliable parameters for evaluation.

- **Good response** to oxygen therapy is associated with (1) arterial oxygen saturation (SaO_2) above 90%. This can be checked by repeated or continuous measurement of oxygen saturation by a "pulse oximeter", (2) arterial oxygen pressure (PaO_2) above 90 mm Hg. This can be checked by repeated measurement of arterial blood gases (ABG).
- **Poor response** to oxygen therapy is associated with (1) persistent low arterial oxygen saturation (below 85%) in spite of 60-70% oxygen, (2) persistent arterial hypoxemia (below 60 mm Hg) in spite of 60-70% oxygen. In these situations of simple oxygen failure, oxygen should be given through positive pressure support (CPAP or assisted ventilation).

OXYGEN-DERIVED PULMONARY INDICES

In normal conditions, any rise of oxygen concentration (or FIO_2) is accompanied with equivalent rise in PIO_2 , PAO_2 and PaO_2 . For example:

- With air breathing ($\text{FIO}_2 = 0.21$), PaO_2 is 90 mm Hg.
- With 40% oxygen breathing ($\text{FIO}_2 = 0.4$), PaO_2 becomes 180 mm Hg.
- With 60% oxygen breathing ($\text{FIO}_2 = 0.6$), PaO_2 becomes 270 mm Hg.
- With 100% oxygen breathing ($\text{FIO}_2 = 1.0$), PaO_2 becomes 450 mm Hg.

In patients with alveolar pathology, there is a degree of ventilation-perfusion mismatch, and the rise in FIO_2 is not accompanied with equivalent rise in PaO_2 . For instance, if PaO_2 is 50 mm Hg at FIO_2 of 0.21, PaO_2 may become only 80 mm Hg at FIO_2 of 0.6.

To assess the severity of lung pathology and the degree of ventilation-perfusion mismatch, one of several "oxygen-derived pulmonary indices" can be used. These indices can evaluate the degree of intrapulmonary shunt and can allow comparison of different blood gas results at different inspired oxygen concentrations. The most important of these indices are:

- **Arterial/alveolar oxygen ratio ($\text{PaO}_2/\text{PAO}_2$):** Arterial oxygen pressure is measured by blood gas analysis and alveolar oxygen pressure is calculated from the alveolar air equation. The normal ratio is 0.8-0.9. Value below 0.55 indicates a large degree of intrapulmonary shunt. Depending on this ratio a “nomogram” is developed for (1) detection of PAO_2 from FIO_2 and PaCO_2 , (2) detection of $\text{PaO}_2/\text{PAO}_2$ ratio and (3) prediction of PaO_2 at any FIO_2 which helps to decrease arterial blood sampling (see nomogram of $\text{PaO}_2/\text{PAO}_2$).
- **Arterial/Inspired oxygen ratio ($\text{PaO}_2/\text{FIO}_2$):** The normal ratio is 400-450. Value below 250 indicates respiratory failure and intrapulmonary shunt of 15%, and value below 200 indicates an intrapulmonary shunt greater than 20%. A nomogram of predicting the degree of intrapulmonary shunt from $\text{PaO}_2/\text{FIO}_2$ ratio is available and can be easily used (see nomogram of $\text{PaO}_2/\text{FIO}_2$).

COMPLICATIONS

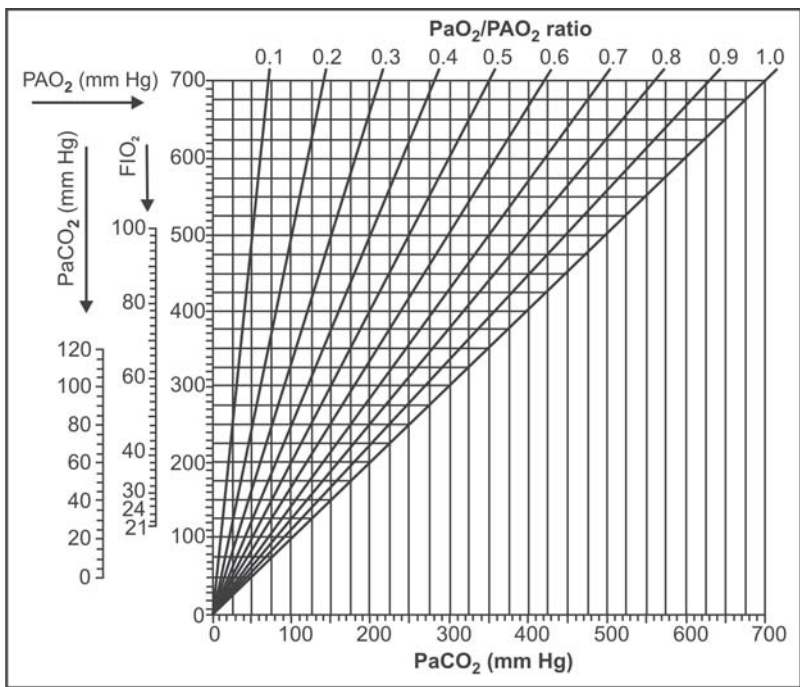
Complications of oxygen therapy are related to both concentration (dosage) and duration of therapy. It is important to note that the pressure of inspired oxygen (PIO_2) and not FIO_2 is the main responsible factor for toxicity.

- **At sea level**, where barometric pressure is 760 mm Hg (or 1 atmospheric), exposure to 100% oxygen is toxic to the lungs in 4 hours. At these circumstances, the pressure of inspired oxygen (PIO_2) equals 713 mm Hg.
- **Below sea level**, where barometric pressure is above 760 mm Hg (or above 1 atmospheric), oxygen toxicity can occur at concentration below 100%. For instance, 21% oxygen is toxic at 6 atmospheric, which makes PIO_2 equals 900 mm Hg.
- **Above sea level**, where barometric pressure is below 760 mm (below atmospheric), 100% oxygen is not toxic. At 1/3 atmospheric pressure, 100% oxygen is safe because PIO_2 is only 235 mm Hg.

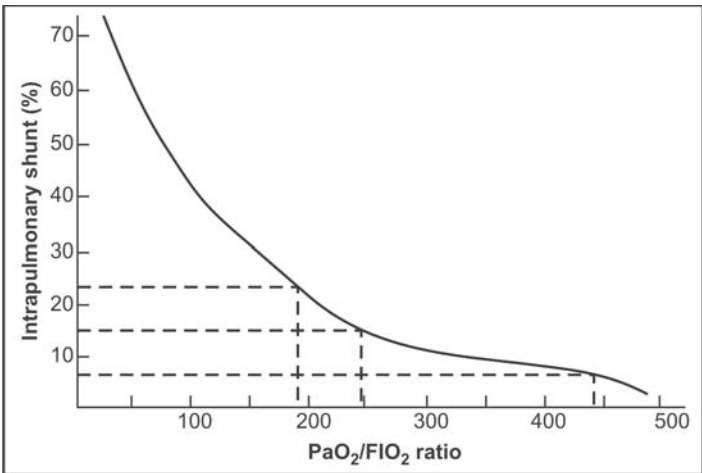
The main toxic effects of oxygen are on retinal structure and lungs.

1. **Eye toxicity:** Retrolental fibroplasia is a systemic oxygen toxicity, which occurs mainly in premature infants due to excessive PaO_2 delivered to retinal artery. In these infants, PaO_2 should never exceed 100 mm Hg, and examination for retrolental fibroplasia should be made at the time of discharge and also 3 to 6 months later.
2. **Lung toxicity:** Pulmonary oxygen toxicity is related to concentration and duration of oxygen therapy. Breathing of 100% oxygen for 4 hours is toxic to the lungs. While 70% oxygen is toxic in 4 days, 40% oxygen is safe for one month. The lung toxicity is manifested by cessation of mucociliary activity, destruction of oxygen-sensitive type I pneumocytes with decreased surfactant production and atelectasis. Hyperplasia of type II pneumocytes and interstitial fibrosis eventually occur. Ventilation-perfusion mismatch also occurs and leads to persistent hypoxemia. Oxygen is particularly serious to mechanically ventilated prematures who may develop bronchopulmonary dysplasia with worsening of pulmonary functions.
3. **Oxygen dependency:** With prolonged oxygen therapy, the patient becomes “oxygen dependent” and weaning becomes very difficult. In these cases, a very gradual withdrawal is important for successful weaning.

Nomogram of arterial /alveolar oxygen ratio ($\text{PaO}_2/\text{PAO}_2$)



Nomogram of arterial /inspired oxygen ratio ($\text{PaO}_2/\text{FIO}_2$)
(For measurement of Intrapulmonary shunt)



51

Chapter

Aerosol Therapy

Liquefaction of secretions

Ultrasonic nebulization of saline (10-15 minutes every few hours)
Usually made before chest physiotherapy and suctioning

Inhalation of medications

Bronchodilators and mast cell stabilizers are the mainly used drugs
Usually given by pressurized atomizers or nebulizers

In contrast to humidification, which means "presence of water in the gaseous state", aerosol means "suspended small particles of a substance (water, saline or drug) in delivered gases". In humidification, the water particle size is 100 micron and the site of deposition is the mouth, nose and larynx. In aerosol therapy, the particle size is smaller (30 micron or less) and the site of deposition is in the large airways, small airways or alveoli depending on the particle size. The smaller the particle size, the more peripheral its site of deposition. The main two indications of aerosol therapy are liquefaction of secretions and inhalation of medications.

LIQUEFACTION OF SECRETIONS

Thick pulmonary secretions can obstruct the small airways and alveoli and can adversely affect the alveolar ventilation and oxygenation. Liquefaction of these secretions, followed by chest physiotherapy and suctioning, is therapeutically useful to clear the airways and to improve oxygenation and ventilation. These simple physical maneuvers can save many patients from being mechanically ventilated.

Normal saline is the most commonly used liquefying agent and it is usually given by ultrasonic nebulization for 10-15 minutes every few hours. Ultrasonic nebulizers deliver very small particles (2-6 microns) which can penetrate the airways to reach the small airways and even the alveoli.

This form of therapy is mainly used in patients with respiratory distress and copious thick secretions, and it is usually made before chest physiotherapy and suctioning.

It is important to remember that adequate systemic hydration (oral or parenteral) is the most efficient way to liquefy airway secretions. Mucolytics may also be used to liquefy secretions.

INHALATION OF MEDICATIONS

Bronchodilators and mast cell stabilizers are the most commonly used inhaled medications. Inhalation can be made by one of two methods depending on the age and patient’s cooperation.

- **Pressurized atomizers or dispensers:** These commonly used inhalers are only suitable for children above the age of 6-8 years. Training and cooperation are important because the metered dose should be delivered during deep inspiration. Children should also be taught to hold their breath for 2-4 seconds after inhalation to obtain efficient deposition of particles in the airways. This method of inhalation therapy can also be used in small children by connecting the inhaler to a "spacer" applied to the face of the child. However, even with cooperative children, as much as 80% of the medication is lost by exhalation and aerosolization into the atmosphere. A small but significant portion of therapeutic effects occurs through sublingual systemic absorption. As the size of particles in this method is 10-30 micron, the site of deposition is in the large airways. The available bronchodilator drugs are either a beta 2 agonist (salbutamol, terbutaline or fenoterol) or anticholinergic drugs (ipratropium). Practical dosage of any of these preparations is 1-2 puffs/dose every 4-6 hours. Salbutamol (Ventolin inhaler) is the most commonly used drug.
- **Nebulizers:** This method is suitable for infants and young children and it has the advantage of delivering small particle sizes (2-6 micron), which can reach the small airways and the alveoli. The calculated dose of the drug (usually 0.25-0.5 ml) is added to 2-3 ml saline and put in the nebulizer to be inhaled through a face mask. The most commonly used nebulized drugs are salbutamol (Ventolin), atropine, adrenaline and ketotifen (Intal).

Comparison between humidification and aerosol therapy

	Humidification	Aerosol therapy	
		Atomization	Nebulization
Inhaled substance	Water	Drugs	Drugs Water, saline
Size of particles	100 micron	10-30 micron	2-6 microns
Site of deposition	Mouth, nose and larynx	Large airways	Small airways and alveoli
Uses	With oxygen therapy In laryngeal stridor	Bronchial asthma	Bronchial asthma Liquefying secretions
Types	Bubbler humidifiers Heating humidifiers	Pressurized inhalers	Acorn nebulizers Ultrasonic nebulizers

52 Chapter

Chest Physiotherapy and Suctioning

Chest physiotherapy

- Postural drainage (different positions to drain different segments)
- Chest percussion or clapping (to enhance drainage by shaking secretions)
- Vibration (to enhance drainage by shaking secretions)
- Deep breathing exercises (to mobilize secretions and to induce coughing)

Suctioning

- Oral cavity and oropharyngeal suctioning
- External nares and nasopharyngeal suctioning
- Endotracheal suctioning (blind or through endotracheal tube)

Chest physiotherapy and suctioning are simple and effective measures that remove pulmonary secretions, clear respiratory passages and improve alveolar ventilation. They are mainly indicated in patients with excessive or thick pulmonary secretions and in those with endotracheal intubation to prevent tube obstruction. As these techniques are stressful and may precipitate cardiopulmonary arrest especially in critically sick children, two precautions are important:

- **Hyperoxygenation:** 100% oxygen for 30 seconds before and after these techniques is important to avoid hypoxemia. This can be given by tight nonrebreathing face masks, bag and mask ventilation or bag and tube ventilation (in ventilated patients).
- **Close observation:** Monitoring of heart rate, respiratory rate and level of consciousness during these techniques is important. If bradycardia, slow respiration or decreased responsiveness occurs (signs of pre-arrest, decompensation), these maneuvers should be discontinued and hyperoxygenation with 100% oxygen should be made.

Two operators are usually required for effective techniques. The first operator is responsible for hyperoxygenation and chest physiotherapy and the second operator is responsible for suctioning.

Practical steps of chest physiotherapy and suctioning

Steps	Operator 1	Operator 2
Step 1	Hyperoxygenation	Catheter preparation
Step 2	Chest physiotherapy	Suctioning
Step 3	Hyperoxygenation	Catheter washing
Step 4	Chest physiotherapy	Suctioning
Step 5	Hyperoxygenation	Catheter washing

- With endotracheal intubation, steps 6 and 7 should be added because endotracheal suctioning is ideally made in 3 positions (head neutral, head to right, head to left).

CHEST PHYSIOTHERAPY

Chest physiotherapy (CPT) consists of simple physical maneuvers that help in mobilization and removal of pulmonary secretions and improvement of alveolar ventilation. Postural drainage and percussion and the most commonly used maneuvers. Deep breathing exercises are only useful in older cooperative children. It is important to remember that the used maneuver or maneuvers should be individualized depending on the patient's condition, and a plan regarding the timing and length of sessions should be made.

Postural drainage

Postural drainage depends on the theory that when a specific segmental bronchus is placed in a vertical position distal to that segment, gravitational forces will assist to mobilize pulmonary secretions from peripheral small airways to the main bronchi, where expectoration or suctioning can complete the removal process. The more viscid the secretions, the slower the rate of flow. Postural drainage can be repeated several times per day depending on the amount of secretions and the rate of re-accumulation.

Chest percussion or clapping

Chest percussion or clapping aims to enhance drainage by shaking secretions from the walls of the airways. It is usually done in conjunction with postural drainage. A cupped hand or tight facemask can be used for percussion to create air vibration that are transmitted to lung tissues. It should be remembered that the infant's chest wall is not as thick as adult's chest, therefore, a more gentle percussion is required. On areas too small for hand percussion, finger percussion can be used. Percussion should be only applied to areas of the chest corresponding to rib cage and should not be applied over the sternum, clavicles, scapulae or vertebrae. A towel can be placed over the chest to increase patient's comfort.

Vibration

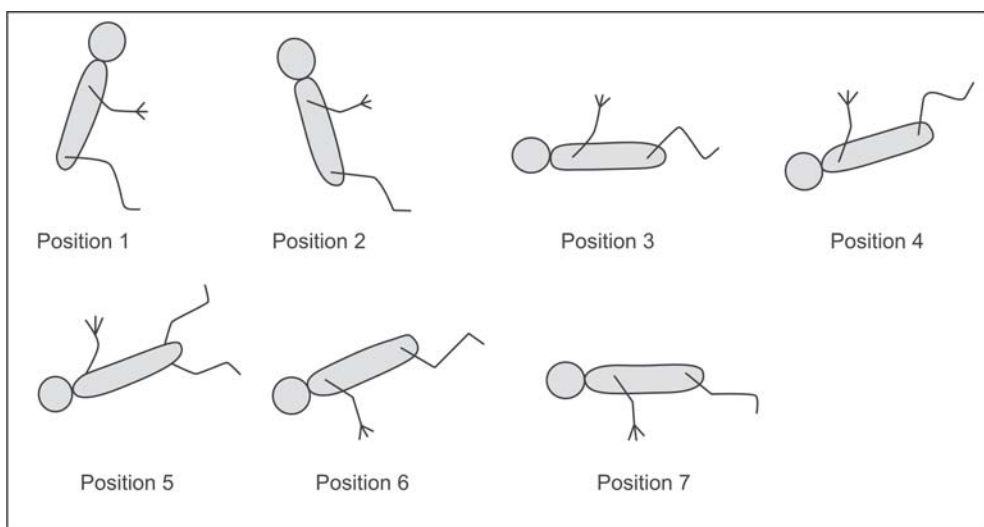
Vibration is a fine shaking motion applied during exhalation after postural drainage and percussion to enhance mobilization of secretions from peripheral airways toward the trachea. It can be done with the hands (in children), palms (in infants) or fingers (in neonates). The older the patient, the more force applied. With a rapidly breathing infant, vibration can be made every second or third exhalation rather than with each breathe. Vibration can also be applied during crying because crying occurs during expiration. Hand electric vibrators are also available and can be used in small infants.

Deep breathing exercises

Deep breathing exercises aim to help mobilization of excessive amounts of secretions and to induce coughing, which further helps in mobilization of secretions. As these exercises need patient cooperation, they are only useful in older cooperative children.

Positioning for postural drainage and percussion of different segments

1. **Upright position (or sitting position) with a 30 degree head-forward**
It drains the apical segments of both upper lobes.
Percussion is made on the upper thorax above the scapula.
2. **Upright position (or sitting position) with a 30 degree head-backward**
It drains the anterior segments of both upper lobes.
Percussion is made on the top of the shoulders and anterior thorax.
3. **Supine position**
It drains the anterior segment of both upper lobes.
Percussion is made on the anterior chest just below the clavicles.
4. **Supine position with a 30 degree head-down**
It drains the anterior basal segments of both lower lobes.
Percussion is made slightly above the lower ribs.
5. **Side-lying positions with a 30 degree head-down**
It drains the lateral basal segments of both lower lobes.
Percussion is made at the lateral thorax at the level of eighth rib.
6. **Prone position with a 30 degree head-down**
It drains the posterior basal segments of both lower lobes.
Percussion is made just above the eleventh and twelfth ribs.
7. **Prone position**
It drains the superior segments of both lower lobes.
Percussion is made below the inferior angle of the scapula.



SUCTIONING

Suctioning of tracheobronchial secretions is indicated in (1) inability to cough effectively as in those with bulbar paralysis or respiratory muscle weakness, (2) inability to mobilize accumulated secretions, (3) obstructed airways by secretions, (4) artificial airway, as endotracheal tube or tracheostomy tube, to keep the airway patent and to prevent tube obstruction.

Equipment

Suctioning can be made by using a portable electric suction apparatus or a vacuum wall outlets. The vacuum canister setup consists of (1) vacuum outlet, (2) manometer to measure vacuum pressure, (3) connecting tubing, (4) collection bottle for drained secretions, (5) connecting tubing to reach from the setup to the patient's bed. The setup should be replaced by sterile equipment every 24 hours.

Suctioning should be made by a sterile suction catheter with appropriate size for the age of the patient (size 5 or 6 for infants and 7 or 8 for children). A good catheter should be pliable and has smooth ends and side holes to minimize mucosal trauma.

Technique

Suctioning should be made under aseptic conditions. Sterile gloves and sterile catheters should be used especially with endotracheal suctioning. Suctioning can be applied to the oral cavity, external flares, oropharynx, nasopharynx or trachea. Endotracheal suctioning can be made through the endotracheal tube or by blind nasotracheal suctioning. Suctioning can be repeated as frequent as necessary depending on the amount of secretions and rate of accumulation.

Rules of endotracheal suctioning

Sterile aseptic technique is essential to avoid pulmonary infections.
Hyperoxygenation with 100 % before suctioning is important to avoid hypoxemia.
Instillation of 1-2 ml saline into the endotracheal tube before suctioning.
Suction catheter should pass easily through the endotracheal tube.
Suction pressure is 60-90 mmHg in infants and 90-120 mmHg in children.
Suction time should never exceed 5 seconds per time.
Suction is made in 3 positions (head neutral, head to right, head to left).
Hyperoxygenation and saline instillation is made before suctioning in each position.
Discontinue and hyperoxygenate if apnea or bradycardia occurs.

Complications

Complications of suctioning include mucosal damage, hypoxemia, hypotension and cardiac arrhythmias. Hypoxemia occurs because oxygen is disconnected and removed secretions and gases are replaced by room air.

53 Chapter

Mechanical Ventilatory Support

Mechanical ventilators

Types: Time-cycled, pressure-cycled, volume-cycled.
Ventilatory system.

Indications

According to necessity: Absolute and relative.
According to system: Respiratory, cardiovascular and neurologic.

Modes of support

Constant support: Continuous positive airway pressure (CPAP).
Intermittent support: Partial support: Intermittent mandatory ventilation (IMV).
Total support: Controlled mechanical ventilation (CMV).
Combined support: Constant and intermittent (PEEP+ IMV or CMV).

Ventilatory settings

Initial settings	Should be combined with
Subsequent adjustments	• Clinical evaluation
Weaning	• Laboratory evaluation

Complications

Respiratory: Airway obstruction, pneumothorax, lung collapse, pneumonia.
Cardiovascular: Low cardiac output and hypotension.
Infections: Local and systemic infections.

Practical problems

Fighting the ventilator or patient-ventilator asynchrony.
Persistent poor oxygenation and calculation of oxygenation index.
Difficult weaning.
Extubation failure.

Positive pressure ventilatory support is a temporary measure to support pulmonary function until the patient can breathe adequately without help. This support can be manual or mechanical:

- **Manual ventilatory support:** Human hand is the best ventilator but because of human fatigue, mechanical ventilators were invented. Manual ventilation is indicated in (1) cardiopulmonary arrest, (2) with chest physiotherapy and suctioning, (3) when facilities for mechanical ventilation are not available or when all beds in ICU are occupied. Intermittent manual ventilation with the bag and mask is the simplest form. Bag and tube ventilation is more effective and can be used when experienced personnel in endotracheal intubation and tube care are available.

- **Mechanical ventilatory support:** All ventilators are capable of providing the different modes of support in addition to humidified oxygen therapy. This support can be constant, intermittent, or combined.

VENTILATORS

Ventilators are classified into negative pressure and positive pressure ventilators.

- **Negative pressure ventilators:** These ventilators generate a negative pressure to the chest wall which leads to chest inflation through sucking of air into the lungs. Although this method is physiological and noninvasive, it is almost obsolete because the negative pressure cylinder encircling the chest cage makes observation and nursing difficult. Moreover, a chest X-ray necessitates removal of the patient off the ventilator.
- **Positive pressure ventilators:** These ventilators generate a positive pressure to the upper airways, which pushes the air into the lungs causing chest inflation. Although this method is unphysiological and invasive (necessitates endotracheal intubation), it is the mainly used method because of the easy observation, examination and nursing. Positive pressure ventilators are divided into conventional and high frequency ventilators according to the rate of cycling.
 - a. **Conventional ventilators:** These ventilators, which cycle at slow rates (usually below 60 breaths/minute), are the most commonly used ventilators, and most of the coming discussion is concentrating on these types.
 - b. **High frequency ventilators:** These ventilators are capable of cycling at high rates ranging from 60-3600 breaths/minute. These types are not widely used and there is conflicting data about their efficacy. There are 4 types of HFV:
 - High frequency positive pressure ventilation (HFPPV): 60-150 cycle/minute.
 - High frequency jet ventilation (HFJV): 60-600 cycle/minute.
 - High frequency flow interrupters (HFFJ): 300-1200 cycle/minute.
 - High frequency oscillation (HFO): 60-3600 cycle/minute. It is the most commonly used type. A continuous fresh gas is delivered to the proximal airway to supply O₂ and remove CO₂. The delivered tidal volumes are less than dead space volume (1-3 ml/kg).

Some ventilators can provide "conventional ventilation" and "high frequency oscillation" as well.

Types of conventional ventilators

All conventional ventilators are capable of providing the different modes of support (constant, intermittent or combined) in addition to humidified oxygen therapy (from 21-100%). In spite of that, ventilators differ in several other parameters as the power supply (pneumatic or electric), flow generation (interrupted or continuous flow), initiation of inspiration (assistor, controller or both) and termination of inspiration (depends of preset time, pressure or volume).

The most important parameter, which is clinically relevant is the method by which the ventilator terminates the inspiration. In other words, the mechanism of cycling from inspiration to expiration. The lung inflation during inspiration depends on 4 interrelated variables; (1) flow rate (litres/minute), (2) inspiratory time (in seconds), (3) airway pressure (cm H₂O or mm Hg), (4) tidal volume (in ml). All ventilators can control the flow rate and one of the other three variables (time, pressure or volume).

1. Time-cycled ventilators: In these types, mechanical inspiration is terminated after a preselected inspiratory time elapses. These ventilators are the mainly used types in neonates, infants and young children (examples of these types are Newbort ventilator, Infant star ventilator, Bourns BP 200, Sechrist ventilator, Drager Babylog ventilator).

- **Tidal volume:** The delivered tidal volume depends on the flow rate and inspiratory time [tidal volume (ml) = flow rate (ml/second) x inspiratory time (seconds)]. Tidal volume can be increased by increasing flow rate and/or inspiratory time and can be decreased by decreasing the flow rate and/or inspiratory time (Figure 53.1). However, the actual tidal volume reaching the lungs depends on the patient's airway resistance and lung compliance. In conditions with increased airway resistance (asthma, bronchiolitis) or decreased lung compliance (pneumonia, ARDS), higher settings are needed to inflate the lungs. Some ventilators can measure the actual tidal volume.
- **Airway pressure:** The resultant airway pressure depends on the flow rate and inspiratory time and the airway pressure wave is described as a "sine wave" (Figure 53.2). Most of these ventilators are capable of limiting the peak inspiratory pressure (PIP) and preventing it from exceeding a preselected upper limit (time-cycled pressure-limited ventilators). With pressure limitation, the peak inspiratory pressure (PIP) remains constant until inspiratory time elapses and tidal volume does not increase during this plateau phase. The resultant pressure waveform is described as a "square wave" (Figure 53.3). With release of pressure limitation, airway pressure increases and the wave returns to be a "sine wave".

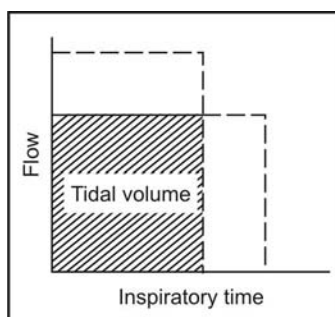


Figure 53.1

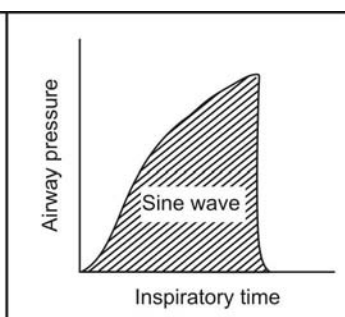


Figure 53.2

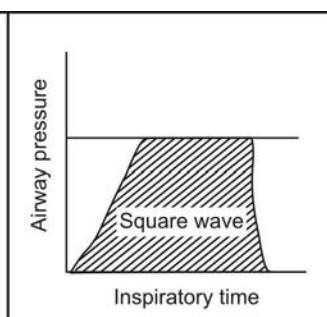
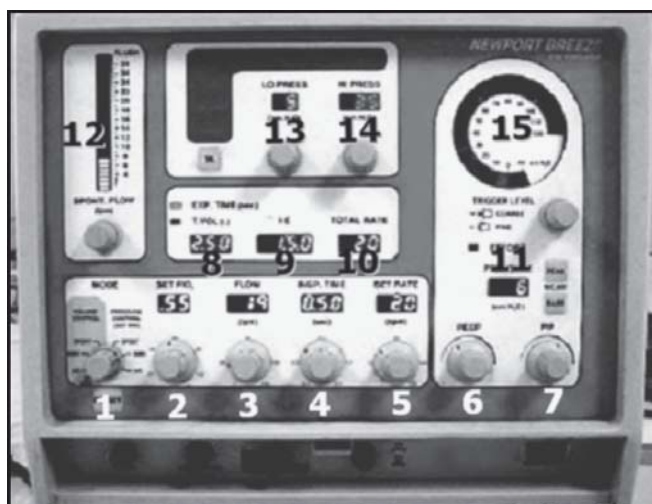


Figure 53.3

2. Pressure-cycled ventilators: In these types, mechanical inspiration is terminated when a preselected airway pressure is reached regardless of the delivered volume or the time elapsed. In these types, tidal volume can be increased by raising the



Time-cycled pressure limited ventilator

Each ventilator has different knobs and displays for control of different parameters:

1. Mode of support: CPAP or IMV.
2. Set FIO_2 : The desired oxygen concentration (ranging from 21% to 100%).
3. Flow: The volume delivered in liters per minute.
4. Inspiratory time: The time of mandated breath in seconds.
5. Set rate: The number of mandated breaths per minute.
6. CPAP or PEEP control: To control the required pressure in cm water.
7. PIP control: It controls the maximum pressure limit during inspiration.
8. Tidal volume: It displays the delivered tidal volume per minute.
9. I/E ratio: It displays the inspiratory/expiratory ratio.
10. Total rate: It displays the total respiratory rate of the patient.
11. PEEP level: It displays the selected PEEP.
12. Spontaneous flow.
13. Low pressure.
14. High pressure.
15. Pressure display: It displays the highest (peak) and lowest pressure (PEEP).

preselected airway pressure. It is important to note that raising the flow rate will decrease the delivered tidal volume because the selected airway pressure is reached earlier.

- These types are also used in neonates and young infants and some ventilators can function as a "time-cycled" and "pressure-cycled" as well.
- There are two major disadvantages of these types, (1) in conditions with increased airway resistance as bronchiolitis and asthma, the preselected airway pressure is reached rapidly and the delivered tidal volume will be small, (2) with any leak in tubing, the preselected airway pressure will not be reached and inspiration will continue leading to pneumothorax.

3. Volume-cycled ventilators: In these ventilators, mechanical inspiration is terminated when a preselected tidal volume is delivered from the ventilator and regardless of airway pressure or time elapsed. The tidal volume can be simply increased or decreased by changing the preselected tidal volume (which is usually 10-15 ml/kg).

- Although these types are the mainly used ventilators in adults and older children, they are not suitable for neonates and infants for 2 reasons; (1) the required tidal volume for these infants is small and most of the selected volume will be lost in the tubing system, (2) with conditions characterized with stiff lungs as hyaline membrane disease and severe pneumonia, most of the delivered tidal volume will be compressed in the breathing circuit tubing and humidifier and almost nothing will reach to the patient's lungs.

Unfortunately, all ventilators are blind and they terminate inspiration without seeing if the delivered volume is appropriate for the patient or not. Therefore, the skills of the operator, and not the ventilator, are the most important factor in successful ventilatory support. Proper understanding of the ventilator mechanics, pathological condition of the patient and ventilator-patient relationship are all essential for successful therapy.

Ventilatory system

The ventilatory system consists of the following:

- 1. Oxygen and compressed air:** The ventilator should be connected to an oxygen source and a compressed air source. Oxygen blender or mixer mixes oxygen and compressed air to deliver the desired oxygen concentration (from 21-100%) into the ventilator circuit. It is usually built-in with the ventilator.
- 2. Electricity connection:** All recent ventilators are electrically operated.
- 3. Ventilator:** It controls the flow rate (litres/minute) and the mode of support (constant, intermittent or combined).
 - With constant pressure support (continuous positive airway pressure or CPAP), the airway pressure (cm H₂O) can be selected.
 - With intermittent pressure support (IMV or CMV), the delivered tidal volume can be adjusted by the flow rate and inspiratory time. The ventilation rate (breaths/minute) can be adjusted as desired. The resultant airway pressure is displayed on a pressure manometer and an upper limit of airway pressure can be selected.
 - With combined pressure support, both the constant support (PEEP) and the intermittent support (IMV or CMV) can be adjusted according to the desired settings.

Most ventilators have several alarming systems against (1) power failure, (2) low gas pressure (oxygen or air), (3) low and high airway pressure, (4) too long inspiratory time, (5) apnea.

- 4. Humidifier:** It humidifies the air and oxygen mixture. Some humidifiers are capable of heating the gas mixture to a preselected temperature.

5. **Patient breathing circuit:** It has inspiratory and expiratory limbs. The inspiratory limb carries the gas flow from the ventilator to the patient while the expiratory limb allows spontaneous expiration after the delivered mechanical inspiration. The circuit also allows spontaneous breathing between the mechanical breaths.

Ventilatory system



The ventilatory system has five main components:

1. **Oxygen and compressed air:** The oxygen blender of the ventilator mixes the oxygen and compressed air to deliver the desired oxygen concentration.
2. **Electricity connection.**
3. **Ventilator:** It has several knobs to control the different parameters of positive pressure support.
4. **Humidifier:** It humidifies the blended mixture of oxygen and compressed air before being delivered to the patient. All humidifiers of ventilators are also capable of heating to deliver heated humidified mixture.
5. **Patient breathing circuit:** This tubing system has two limbs; inspiratory and expiratory. The inspiratory limb (A) extends from the ventilator to the humidifier then from the humidifier to the endotracheal tube connector of the patient. The expiratory limb (B) extend from the endotracheal tube connector back to the ventilator.

VENTILATORY SUPPORT

It may be wise to repeat the words of one author who said "mechanical ventilation can be the breath of life and can also be the blow of death". Therefore, mechanical ventilation should be only carried out by personnel experienced in endotracheal intubation and who understand the mechanics of the used ventilator and the ventilator-patient relationship.

Indications

Mechanical ventilatory support is indicated when other simple measures of respiratory support (oxygen, aerosol, chest physiotherapy and suctioning) are not effective to improve oxygenation and/or ventilation. Indications can be classified according to necessity (absolute, relative), system involvement (respiratory, cardiovascular, neurologic) or the required mode of support (CPAP, IMV or CMV).

Indications of mechanical ventilatory support

According to necessity

Absolute indications: Apnea, persistent hypoxemia, severe hypoventilation and markedly elevated intracranial pressure.

Relative indications: Shock states, deep coma and refractory status epilepticus.

According to system

Respiratory: Apnea, persistent hypoxemia, severe hypoventilation.

Cardiovascular: Severe shock states.

Neurologic: Markedly elevated intracranial pressure, status epilepticus.

Modes of support

Mechanical positive pressure support can be constant (CPAP), intermittent (IMV or CMV) or combined (IMV or CMV + PEEP). Each of these modes has its own indications.

Indications of different modes of ventilatory support

Continuous positive airway pressure (CPAP)

Persistent low arterial oxygen saturation (below 85%) in spite of 70% oxygen.

Persistent low PaO_2 (below 60 mm Hg) in spite of 70% oxygen.

To decrease the work of breathing in acute bronchiolitis or pneumonia.

During weaning from IMV.

Intermittent mandatory ventilation (IMV)

Failure of CPAP to improve oxygenation (persistent low saturation and low PaO_2).

Hypoventilation with PaCO_2 above 60 mm Hg, rising PaCO_2 , low pH below 7.2.

Shock states or deep coma to ensure adequate oxygenation.

Controlled mechanical ventilation (CMV)

Failure of IMV to improve oxygenation and ventilation.

Type II respiratory failure (apnea, neuromuscular respiratory paralysis).

Markedly increased intracranial pressure (therapeutic hyperventilation).

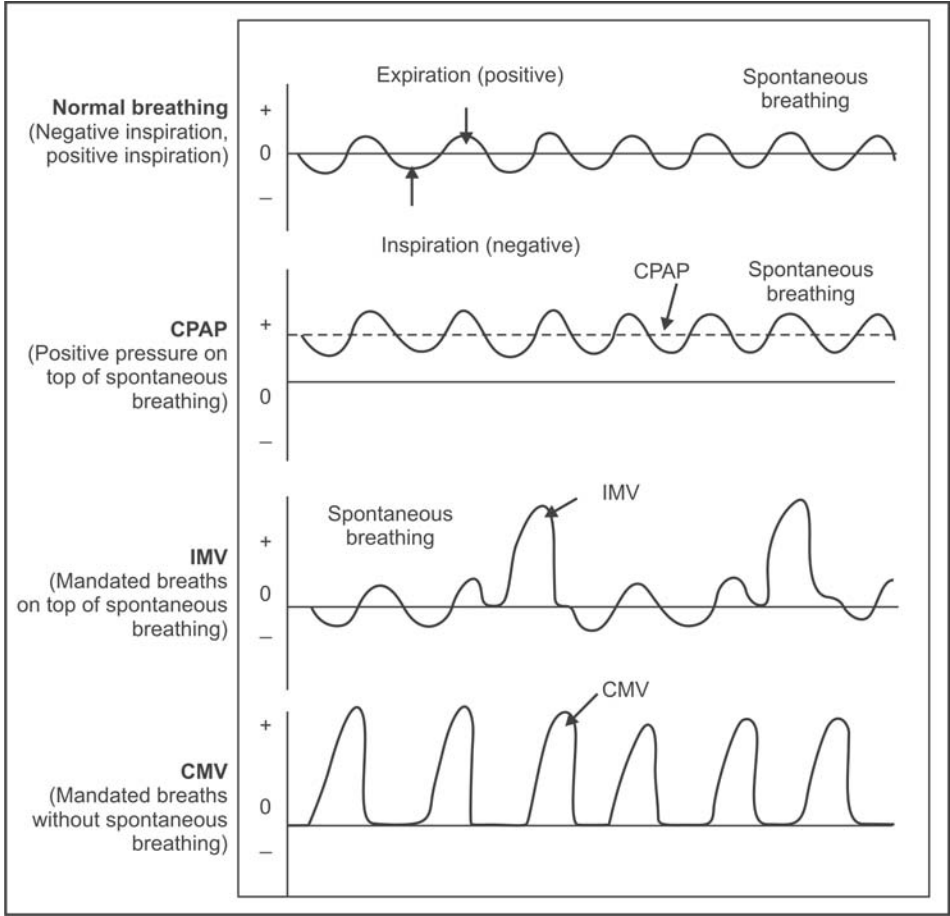
1. **Continuous positive airway pressure (CPAP):** In normal spontaneous breathing, the airway pressure is negative during inspiration (to bring air in), positive during expiration (to push air out) and zero at the end of inspiration and expiration. Continuous positive airway pressure is a form of constant pressure support applied to spontaneously breathing patient to keep the airway pressure positive throughout the respiratory cycle. Its main value is the improvement of oxygenation through increasing the functional residual capacity (FRC) and distention of the atelectatic and poorly ventilated alveoli. These effects will improve ventilation-perfusion matching and decrease the work of breathing.

- **Indications:** CPAP is mainly indicated when simple oxygen therapy fails to improve the defective oxygenation. Persistent low arterial oxygen saturation (below 85%) and/or arterial hypoxemia (PaO_2 below 60 mm Hg) in spite of 70% oxygen is the main indication. Severe pneumonia, severe bronchiolitis, pulmonary edema and respiratory distress syndrome (neonatal or adult type) are the main indications. CPAP may also be used to decrease the work of breathing in patients with severe respiratory distress. Decreased work of breathing will save the energy and oxygen consumed by the overworked respiratory muscles and will also delay or prevent the occurrence of respiratory muscle fatigue. CPAP is also used during weaning from intermittent support.
 - **Methods of applications:** CPAP can be noninvasive or invasive; it can be applied through a nasal cannula or nasal prongs (nasal CPAP), nasopharyngeal catheter (nasopharyngeal CPAP) or endotracheal tube (endotracheal CPAP). Treatment can be started with nasal or nasopharyngeal methods, and invasive endotracheal CPAP can be used when simple methods are not effective.
 - **Applied pressure and oxygen:** A constant pressure of 4-6 cm H_2O is usually given in addition to 40-70% oxygen. Higher pressures above 7-8 cm H_2O are serious and may lead to pneumothorax or impairment of venous return.
 - **Evaluation of response:** Good response to CPAP is associated with improved arterial oxygen saturation (above 90%), improved PaO_2 (above 80-90 mm Hg) and decreased work of breathing. CPAP failure (persistent low saturation and low PaO_2) is an indication for intermittent mandatory ventilation (IMV).
2. **Intermittent mandatory ventilation (IMV):** It is a form of partial intermittent pressure support applied to spontaneously breathing patient. A number of mandated (obligatory) breaths per minute, usually less than the respiratory rate of the patient, are given. In other words, the ventilatory process is partially made by the mandated breaths delivered by the ventilator and partially by the patient's spontaneous efforts. IMV aims to improve oxygenation (PaO_2 rise), to improve ventilation (PaCO_2 fall) and to decrease the work of breathing. Some ventilators are capable of delivering the mandated breaths only during inspiration (synchronized IMV or SIMV). Although the idea seems attractive, SIMV has no practical advantage over the ordinary IMV.
- **Indications:** IMV is mainly indicated in (1) CPAP failure (persistent low arterial oxygen saturation and low PaO_2 in spite of 7-8 cm H_2O pressure and 70% oxygen), (2) alveolar hypoventilation with PaCO_2 above 50-60 mm Hg or rising PaCO_2 , (3) severe respiratory or combined respiratory and metabolic acidosis with pH below 7.2, (4) severe shock states and deep coma to ensure adequate oxygenation of vital organs.
 - **Methods of applications:** IMV is mainly given through the endotracheal tube. Therefore, endotracheal intubation is the first step. Noninvasive ventilation through face masks, nasal catheter or nasopharyngeal tube may be used in neonatal apnea, difficult intubation, difficult weaning and extubation failure.

- **Ventilatory settings:** The delivered tidal volume and the ventilatory rate depend on the patient's condition and the response to the initial settings. Oxygen concentration (40-70%) is also given. IMV is usually combined with a constant support to keep the airway pressure positive during the end of expiration (positive end expiratory pressure or PEEP). PEEP is similar to CPAP but the term is used when the constant support is given in addition to the intermittent support (see below).
 - **Evaluation of response:** Good response to IMV is associated with improved arterial oxygenation (PaO_2 rise), improved alveolar ventilation (PaCO_2 fall) and decreased work of breathing. IMV failure (persistent poor oxygenation and/or persistent hypo-ventilation) is an indication for controlled mechanical ventilation.
3. **Controlled mechanical ventilation (CMV):** In this form of total intermittent support, the ventilator controls the whole process of ventilation without depending on the patient's spontaneous efforts. The number of mandated breaths per minute is equal or even exceeding the respiratory rate of the patient, and the patient's spontaneous efforts between the mandated breaths are either absent or ineffective. This form of support is also usually combined with a constant support (PEEP).
- **Indications:** CMV is mainly indicated in (1) failure of IMV to improve oxygenation and ventilation due to either incoordinated mandated and spontaneous breaths (patient is fighting the ventilator) or markedly increased work of breathing. In these conditions, the patient is strongly sedated (with sedatives) or even paralyzed (with pancuronium) and ventilation becomes totally controlled by the ventilator, (2) type II respiratory failure due to CNS depression (apnea) or neuromuscular respiratory paralysis (as Guillain Barre syndrome or poliomyelitis), (3) markedly increased intracranial pressure where mechanical hyperventilation is a rapid therapeutic measure to lower the increased intracranial pressure.
 - **Methods of application:** CMV is mainly given through the endotracheal tube. Noninvasive ventilation (face mask, nasopharyngeal catheter) may be considered in neuromuscular paralysis.
 - **Ventilatory settings:** The delivered tidal volume and the ventilatory rate depend on the patient's condition and the response to initial settings. It is also usually combined with a constant support (PEEP).
 - **Evaluation of response:** Good response to CMV is associated with improved arterial oxygenation and alveolar ventilation. Poor response can be due to severe anemia, severe shock, pulmonary hypertension or severe degree of ventilation-perfusion mismatch.

Types of ventilation and airway pressure in positive pressure support

	Type of ventilation	Airway pressure
Normal breathing	Spontaneous	Negative during inspiration and Positive during expiration
CPAP	Spontaneous	Continuous positive
IMV	Spontaneous and mechanical	Spontaneous (-ve and +ve) Mechanical (Positive)
CMV	Mechanical only	Positive



Ventilatory settings

It is important to remember that the main three objectives of mechanical ventilatory support are (1) to improve oxygenation, (2) to improve alveolar ventilation, (3) to decrease the work of breathing (to save oxygen and to prevent respiratory muscle fatigue). The selected ventilatory settings should be directed and adjusted to achieve these objectives.

It is also important to know that there is no magic formula that can precisely suggest or predict the appropriate settings of an individual patient. Although general guidelines are available, the skills of the operator remain as the most important factor in successful ventilatory support. In fact, the ventilator should be viewed as a "piano" and not a "TV set", where knowledge, experience and skills of the player are important for smooth and successful operation.

The process of mechanical ventilatory support can be divided into three stages (initial settings, subsequent settings and weaning). With each stage, clinical and laboratory response of the selected settings should be evaluated.

1. **Initial ventilatory settings:** The different ventilatory settings can be divided into; (1) settings to improve oxygenation (FIO_2 , CPAP or PEEP), and (2) settings to improve alveolar ventilation (rate, tidal volume). In time-cycled ventilators, tidal volume can be calculated by the flow rate (litres/minute) and the inspiratory time (in seconds). The inspiratory/expiratory ratio (I/E ratio) should be kept in the range of 1:2 or 1:3. The expiratory time can be derived by subtracting the inspiratory time from the duration of each cycle ($60/\text{rate}$). For example, if the ventilatory rate is 30 breaths/minute, the duration of each ventilatory cycle is 2 seconds ($60/30$), and if inspiratory time is 0.5 second, the expiratory time will be 1.5 seconds and I/E ratio is 1:3. The highest airway pressure during inspiration (peak inspiratory pressure or PIP) should be limited (not to exceed 25-30 cm H_2O) to avoid pulmonary barotrauma (pneumothorax).

Suggested initial ventilatory settings

Settings to improve oxygenation

Oxygen concentration (or FIO_2): 60-70% (0.6-0.7).

Constant pressure support (CPAP or PEEP): 4-5 cm H_2O .

Settings to improve alveolar ventilation

Rate: Select the normal rate for age.

Tidal volume (usually 10-15 ml/kg). It depends on flow and inspiratory time.

- Flow: About 2 litres/kg/minute.
- Inspiratory time: 0.5-0.7 seconds.
- Expiratory time: Should be longer than inspiratory time.
- Inspiratory/expiratory ratio (I/E ratio): 1:2 or 1:3.

Peak inspiratory pressure (PIP): Should be limited to 25-30 cm H_2O .

- Oxygenation is also improved by increasing the tidal volume. This explains why IMV or CMV are used in CPAP failure.

2. **Subsequent ventilatory adjustments:** Initial ventilatory settings should be immediately followed by clinical and laboratory evaluation to assess the adequacy of oxygenation and ventilation. With this evaluation, the patient can be described as appropriately supported, undersupported or oversupported.

- **Assessment of oxygenation** is made by (1) observing the color, (2) measurement of arterial oxygen saturation (SaO_2), (3) measurement of arterial oxygen pressure (PaO_2). Adequate oxygenation is associated with pink coloration,

arterial oxygen saturation above 90% and PaO_2 above 80 mm Hg. Poor oxygenation can be corrected by increasing oxygen concentration and/or CPAP or PEEP. It is important to remember that CPAP or PEEP above 7-8 cm H_2O is serious and may lead to pneumothorax.

- **Assessment of alveolar ventilation** is made by (1) observing chest expansion (2) auscultating air entry, (3) measurement of PaCO_2 . Adequate alveolar ventilation is associated with adequate chest expansion, good air entry and PaCO_2 between 35-45 mm Hg. Hypoventilation can be corrected by increasing the rate and/or the tidal volume. If chest expansion is inadequate, tidal volume can be increased by increasing the flow rate or the inspiratory time. On the other hand, if chest expansion is adequate, hypoventilation can be corrected by increasing the rate. Prolongation of inspiratory time should not exceed one second and I/E ratio should not exceed 1:1 (ideal ratio is 1:2). Marked chest expansion and/or long inspiratory time are serious and can lead to pulmonary barotrauma (pneumothorax) and impaired venous return (poor perfusion).
- **Assessment of work of breathing:** The patient's respiratory efforts (respiratory rate, retractions) and the coordination between spontaneous and mechanical ventilation should be evaluated. A good support is associated with decreased work of breathing (rate, retractions). It is important to remember that in acute hypoxemic respiratory failure, more than 50% of total oxygen consumption is utilized by respiratory muscles and reduced work of breathing in these cases is important to improve oxygenation.
- **Special considerations:** The nature of the underlying disease should be considered while choosing the various ventilatory settings:
 - In conditions with increased airway resistance as acute bronchiolitis and acute asthma, the expiratory time should be long to allow expiration and to avoid air trapping which can lead to pneumothorax. I/E ratio should be 1:3 or even 1:4. In addition, PEEP should not exceed 4-5 cm H_2O .
 - In conditions with decreased lung compliance as pneumonia and respiratory distress syndrome, I/E ratio of 1:2 or even 1:1 can be used and PEEP can be increased to 7-8 cm H_2O when necessary. The differences between these two groups are related to the time constant (time necessary for the lungs to inflate and deflate). Time constant = airway resistance x lung compliance. Therefore, it is increased with increased airway resistance and decreased with decreased lung compliance.
 - In conditions with normal lungs as CNS respiratory depression and neuromuscular respiratory paralysis, adequate chest expansion can be achieved by a relatively low ventilatory settings. As oxygenation is not a problem in these patients, high levels of oxygen concentration is unnecessary and high levels of PEEP should be avoided because it increases the intracranial pressure.

Lung mechanics in mechanical ventilation

Normal lungs

- Normal compliance.
- Normal airway resistance.
- Normal time constant.
(i.e. normal inflation and deflation times)
- Average pressure is needed for ventilation.
- I: E ratio can be 1:2 or 1:3.

Stiff lungs

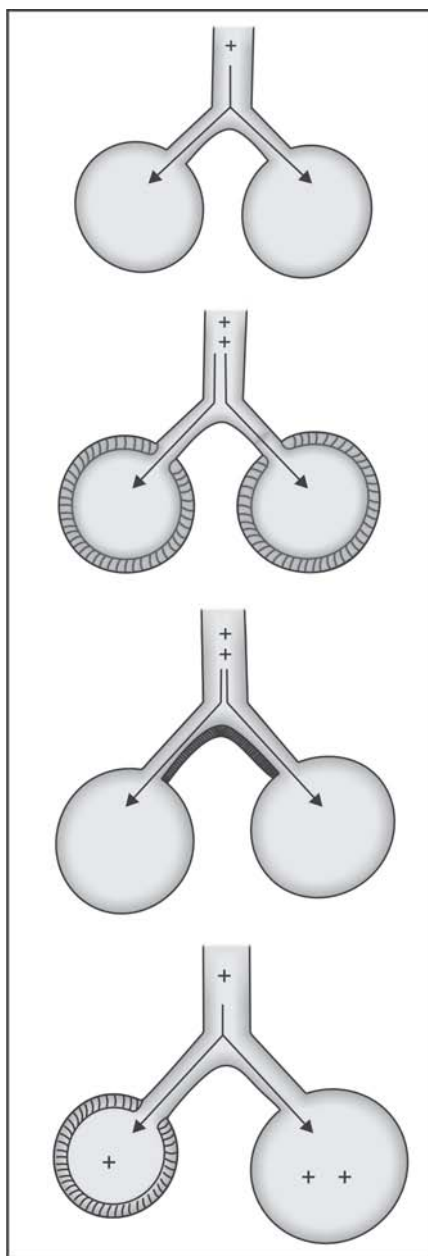
- Decreased compliance
- Normal airway resistance
- Short time constant
(i.e. short inflation and deflation times)
- Higher pressure is needed for ventilation
- I: E ratio can be increased to 1: 2 or 1:1.
- PEEP can be increased to 7-8 cm H₂O.

Narrow airways

- Normal compliance
- Increased airway resistance
- Long time constant
(i.e. long inflation and deflation times)
- Higher pressure is needed for ventilation
- I: E ratio should be decreased to 1:3 or 1:4.
- PEEP should not exceed 4-5 cm H₂O

Unilateral pathology

- Unilateral decreased compliance
- Normal airway resistance
- Unilateral short time constant
- Uneven ventilation
(i.e. more inflation of the normal side).



Evaluation of initial ventilatory settings and subsequent adjustments

Appropriately supported patient

Adequate oxygenation and ventilation with decreased work of breathing.

- Keep initial settings and reevaluate later.

Under-supported patient

Inadequate oxygenation (low PaO_2) and/or hypoventilation (PaCO_2 above 50 mm Hg).

- Improve oxygenation with increasing FIO_2 and PEEP.
- Improve ventilation by increasing rate and/or tidal volume (flow and inspiratory time).

Over-supported patient

Hyperoxygenation (PaO_2 above 100 mm Hg) and/or hyperventilation (PaCO_2 below 30 mm Hg).

- Decrease oxygenation by decreasing FIO_2 and PEEP.
- Decrease ventilation by decreasing rate and/or tidal volume (flow and inspiratory time).

3. **Weaning:** The duration of mechanical ventilatory support is mainly related to the underlying pathology. It can be only for few or several days as in pneumonia or acute bronchiolitis and it may extend for several weeks as in bronchopulmonary dysplasia or respiratory muscle paralysis. Weaning is the gradual withdrawal of the mechanical ventilatory support and resumption of spontaneous breathing.

- **When:** The criteria to start the weaning process include (1) improvement of the underlying pathology, (2) stable and satisfactory oxygen saturation and arterial blood gases, (3) stable cardiovascular, neurologic and metabolic condition.
- **How:** As a rule, withdrawal of support should be gradual and only one parameter is changed at a time. With each change, clinical and laboratory evaluation of the patient's condition is important, and the next change is only made when the previous one is well tolerated by the patient. It is important to know that there is no hard rules of the weaning process that can be applied to every patient, therefore, the steps and duration of weaning process should be individualized according to the patient's condition.

Guidelines for practical steps of weaning

1. Change the mode of support from CMV to IMV

Discontinue sedatives and/or neuromuscular blocking agents (as pancuronium).
Decrease ventilatory rate to allow spontaneous breathing.

2. Decrease the minute ventilation (tidal volume X rate)

Decrease inspiratory time to decrease tidal volume and to lower PIP.
Decrease ventilatory rate gradually to 3-4 breaths/minute.

3. Decrease the oxygen support

Decrease PEEP to 3-4 cm H_2O and decrease oxygen concentration to 40-50%.

4. Switch the ventilator to CPAP mode

CPAP: 3-4 cm H_2O and Oxygen: 40-50%.

5. Extubation and oxygen therapy

Hyperoxygenation with the bag and tube immediately before extubation.
Remove the tube while applying pressure through the connected bag.
Give oxygen therapy 10% higher than the concentration with CPAP (50-60%).
Be ready for reintubation if clinical deterioration occurs.

4. Complications

Complications of mechanical ventilatory support can be caused by:

- Endotracheal tube: Traumatic injury, obstruction, malposition, infection.
- Ventilatory system: Power failure, disconnection, kinking of tubing.
- Ventilatory settings: High pressures, long inspiratory time, short expiratory time.
- Patient: Underlying pathology, fighting the ventilator, self-extubation.

Fortunately, most of these complications are preventable and can be avoided by the proper care of endotracheal tube, checking of the ventilatory system, skilled choice of ventilatory settings and careful observation of the patient.

Precautions to avoid complications of mechanical ventilation

Endotracheal tube

Careful intubation to avoid injury of the larynx and trachea.
Proper fixation in the correct position to avoid displacement or accidental extubation.
Suctioning every 1-2 hours to avoid tube obstruction.
Strict sterile techniques to avoid infections.

Ventilatory system

Check electrical connection and gas pressures.
Check humidifier for water level and gas temperature.
Check breathing circuits to avoid disconnection and kinking of tubing.
Remove condensed water from the breathing circuit.

Ventilatory settings

Avoid high pressures (PIP above 30, CPAP or PEEP above 8).
Avoid long inspiratory time to prevent overdistention of alveoli and pneumothorax.
Avoid short expiratory time to prevent air trapping and pneumothorax.

Patient

Consider sedation or muscle paralysis if the child is fighting the ventilator.
Restrict the movements of the hands to prevent self-extubation.

Complications of mechanical ventilation are mostly related to the respiratory system. Cardiovascular compromise and infections are also major risks that should be considered.

1. Respiratory complications: Airway obstruction and pneumothorax are the most serious life-threatening complications. Other complications include lung collapse, pulmonary interstitial emphysema, pneumonia and bronchopulmonary dysplasia. Subglottic stenosis and nodularity of vocal cords may occur with prolonged intubation.

- Airway obstruction:** With mechanical ventilation, the life of the patient depends on the patency of endotracheal tube. Obstruction of the tube by mucous plugs or due to tube kinking leads to sudden deterioration of oxygenation and ventilation. Tube obstruction can be only partial and lead to gradual deterioration. The condition should also be suspected when higher settings are needed to produce adequate chest expansion. Obstructed tube should be immediately replaced by a new one.

- b. Pneumothorax:** This common complication can occur due to overdistention and rupture of the alveoli which may result from one or more of several reasons; (1) high airway pressure (PIP above 30 cm H₂O, CPAP or PEEP above 8 cm H₂O), (2) long inspiratory time (more than one second), (3) short expiratory time which leads to insufficient expiration and air trapping, (4) malposition of endotracheal tube into the right main bronchus which leads to uneven ventilation and pneumothorax of the right side, (5) improved lung pathology without reduction of ventilatory settings, (6) inadequate humidification and/or low gas temperature which can lead to dryness of mucosa, (7) uneven or unilateral lung pathology which leads to overdistention and rupture of the normal alveoli.
- Large or tension pneumothorax leads to sudden deterioration of oxygenation and ventilation. Obstructive shock with hypotension and high CVP may also occur. Rapid drop of arterial oxygen saturation or PaO₂ should always suggest the condition and a picture of combined metabolic and respiratory acidosis may be present. Physical findings over the affected side include unilateral bulge, increased resonance on percussion, decreased air entry and mediastinal shift to the other side. Diagnosis should be immediately confirmed by an urgent chest X-ray.
 - Closed intercostal drainage should be immediately done in the fifth intercostal space in the midaxillary line and the tube should be left in place for 72 hours or for 24 hours after it is no longer bubbling. Clamping of the tube for 12-24 hours before removal is recommended.
- c. Lung collapse:** Massive collapse of the left lung occurs if the endotracheal tube is displaced into the right main bronchus. Simple withdrawal of the tube to the correct position results in re-expansion of the collapsed lung. Right upper lobe collapse may occur following extubation especially with nasotracheal intubation.
- d. Pneumonia:** It is a common problem in ventilated patients and the risk increases with the duration of ventilation. The possibility should be considered in the following situations; (1) gradual deterioration of oxygenation and ventilation, (2) increased work of breathing, (3) increased bronchial secretions, (4) appearance of fever and/or leukocytosis. Blood culture and culture of tracheal aspirate or the tip of endotracheal tube are important to identify the causative organism. Vigorous combined parenteral antibiotic therapy is indicated.
- e. Bronchopulmonary dysplasia:** This complication occurs in about 20% of ventilated newborns and the incidence is much higher in low birth weight babies. Hyperoxia, high airway pressure, inflammation and probably infection are the major contributing factors. Chronic respiratory distress and gradual deterioration of oxygenation and ventilation are the main presentations. Treatment includes drug therapy (steroids, diuretics, bronchodilators) and very gradual withdrawal of respiratory support.

- f. Pulmonary interstitial emphysema:* This complication should be considered when gradual deterioration of oxygenation and ventilation is associated with fine inspiratory crepitations. The presence of air in pulmonary interstitial tissues can be detected radiologically. Reduction of airway pressures (PIP and PEEP) is important to avoid its progression to pneumothorax.
2. **Cardiovascular compromise:** Decreased cardiac output and hypotension may occur with high levels of CPAP or PEEP due to the increased intrapleural pressure and the impairment of venous return and cardiac filling. Increased pulmonary vascular resistance and right ventricular afterload is another factor responsible for the decreased cardiac output. Adverse clinical effects of these changes include; (1) sudden or rapid deterioration with poor peripheral perfusion and hypotension, (2) increased intracranial pressure due to impairment of cerebral venous return, (3) impaired renal and hepatic functions may occur secondary to hypotension and hypoperfusion.
 3. **Infections:** Local and systemic nosocomial infections are major risks in critically ill infants and children. Local infections at the sites of I.V. cannulae and septicemia are common especially with prolonged mechanical ventilation. Strict sterile antiseptic measures are important to avoid infections. Hand washing before and after each examination remains the most simple and most effective measure to guard against infection. Care of endotracheal tube should be done under strict aseptic conditions. Any discovered infection should be vigorously treated with the appropriate antimicrobial therapy.

Causes of deterioration on mechanical ventilation

Sudden or acute deterioration

Total obstruction of the endotracheal tube.
 Pneumothorax.
 Left lung collapse due to intubation of the right main bronchus.
 Cardiovascular compromise due to high levels of PEEP or CPAP.
 Ventilator failure: Power failure, low pressures.
 Accidental disconnection of the patient breathing circuit.

Gradual deterioration

Partial obstruction of endotracheal tube.
 Pulmonary interstitial emphysema.
 Partial lung collapse.
 Pneumonia.
 Bronchopulmonary dysplasia.
 Inappropriate ventilatory settings or fighting the ventilator.

5. Practical problems

The most commonly encountered problems are:

1. **Fighting the ventilator (Patient-ventilator asynchrony):** Spontaneous inspiratory efforts by the distressed infant or child are frequently out of phase with mechanical breaths. This patient-ventilator asynchrony is commonly expressed as 'the patient is fighting the ventilator' and it can be responsible for defective oxygenation or

development of pneumothorax. The use of sedation is helpful in establishing respiratory phase synchronization between the patient and the ventilator. In extreme cases of patient-ventilator asynchrony, neuromuscular paralysis with pancuronium (0.1 mg/kg, I.V.) is indicated to abolish spontaneous respiratory effects. In this case, the patient becomes totally dependent on mechanical ventilatory support. In other words, the mode of support is changed from IMV to CMV.

2. **Persistent poor oxygenation:** Persistent low arterial oxygen saturation and low PaO_2 in spite of high oxygen concentration and high ventilatory settings is mostly due to a high degree of ventilation-perfusion mismatch and intrapulmonary shunting. Oxygenation index (OI) is a reliable index for assessment of severity of lung pathology in mechanically ventilated patients. Calculation of oxygenation index (OI) depends on mean airway pressure (MAP), oxygen concentration ($\text{O}_2\%$) and arterial oxygen pressure (PaO_2). Some ventilators, especially the new models, are capable of computing and displaying the mean airway pressure. Otherwise, it can be calculated from the peak inspiratory pressure (PIP), positive end expiratory pressure (PEEP), inspiratory time (T_i) and expiratory time (T_{ex}).

Calculation and significance of oxygenation index (OI)

Calculation of OI

$$\frac{\text{MAP} \times \text{FIO}_2 \times 100}{\text{PaO}_2}, \text{ where MAP} = \text{PEEP} + \frac{(\text{PIP} - \text{PEEP}) \times T_i}{\text{cycle time } (T_i + T_{ex})}$$

Significance of OI

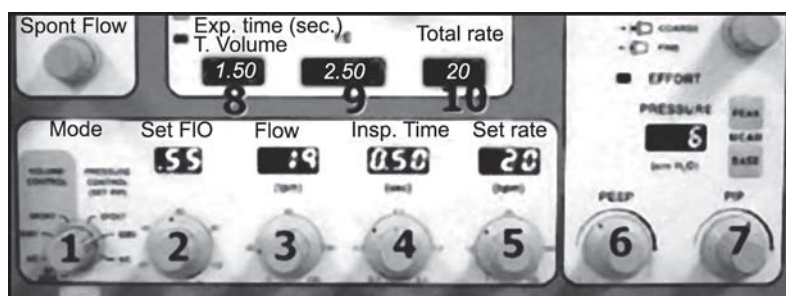
- Value between 1-5: No or minimal lung pathology
- Value between 6-10: Mild lung pathology
- Value between 11-20: Moderate lung pathology
- Value above 20: Severe lung pathology (50% mortality)
- Value above 40: Very severe lung pathology (80% mortality)

- OI above 5 is associated with 40% extubation failure
- OI above 40 is an indication for extracorporeal membrane oxygenation (ECMO)

3. **Difficult weaning:** Weaning from mechanical ventilatory support is occasionally difficult due to persistent lung pathology (as bronchopulmonary dysplasia, pneumonia) or weakness or atrophy of respiratory muscles. The problem is more common with prolonged mechanical ventilation where the patient may become ventilator-dependent. In these situations, trials of weaning are associated with worsening of the clinical status. Initial control of the underlying lung pathology should be followed by a very gradual weaning process. Reduction of ventilatory rate can be as slow as one breath/minute every few or several days. Once the ventilatory rate is 5-10 breaths/minute, alternating periods of CPAP and IMV can be tried during the daytime to allow training of the respiratory muscles. The CPAP trial durations are gradually increased until the patient becomes ventilated at night only. Finally, the night ventilation can be gradually withdrawn by reduction of the hours of ventilation.

4. **Extubation failure:** It is defined as "clinical deterioration within 48 hours of extubation which necessitates re-intubation". The condition may result from airway obstruction due to laryngeal edema, post-extubation lung collapse or persistent significant lung pathology. Ideally, extubation should not be tried if the oxygenation index is above 5 because of the high incidence of extubation failure (40%). In case of laryngeal edema, re-intubation should be made with a smaller tube and corticosteroids are given parenterally for 2 days before extubation is re-attempted.

Practical example



Ventilatory settings of this patient are:

1. Mode of support: CMV (because set rate equals total rate = 20, see numbers 5, 10).
2. Set FIO_2 : 0.55.
3. Flow: 19 litres/minute.
4. Inspiratory time: 0.5 second.
5. Set rate: 20/minute.
6. PEEP: 6 cm H_2O .
7. Peak inspiratory pressure (PIP): 25 cm H_2O .
8. Tidal volume: 2.5.
9. Inspiratory/expiratory ratio (I/E ratio): 1:5.
10. Total rate: 20 breaths/ minute (i.e. no evident spontaneous breathing).

Effects of these settings are:

1. Clinical signs: Pinkish, good chest expansion and good air entry.
2. Arterial oxygen saturation (SaO_2): 99%
3. Arterial blood gases: $\text{pH} = 7.5$, $\text{PaO}_2 = 120$ mm Hg, $\text{PaCO}_2 = 28$ mm Hg.

Comment on these settings: The patient is oversupported because of the hyperoxygenation (PaO_2 above 100 mm Hg), hyperventilation (PaCO_2 below 30 mm Hg) and respiratory alkalosis (high pH and low PaCO_2). Settings should be reduced.

Another example

Calculate oxygenation index in a mechanically ventilated patient with the following settings: PIP = 25, PEEP = 5, $\text{FIO}_2 = 0.6$, $\text{PaO}_2 = 50$ mm Hg, inspiratory time = 0.5 second, ventilatory rate = 30/minute.

- **Calculation of oxygenation index**

1. Cycle time (inspiratory time + expiratory time) = $60 / \text{rate} = 60 / 30 = 2$ seconds.

$$2. \text{ MAP} = 5 + \frac{(25 - 5) \times 0.5}{2} = 5 + \frac{(20 \times 0.5)}{2} = 5 + 5 = 10$$

$$3. \text{ OI} = \frac{(10 \times 0.6 \times 100)}{50} = \frac{600}{50} = 12 = \text{Moderate lung pathology}$$

- **Comment on ventilatory settings:** The patient is undersupported because of the low PaO_2 (50 mm Hg). Higher settings are needed to improve oxygenation.

Flow sheet of respiratory support

[illegible]

54 Acute Peritoneal Dialysis

Chapter

Indications

Acute renal failure: Clinical and laboratory indications

Non renal indications: Severe hyponatremia, hyperammonemia, poisoning

Dialysis solutions and equipment

Dialysis solutions: Different concentrations (1.5%, 2.5%, 4.25%).

Dialysis catheters: Different sizes (adult, child, infant).

Dialysis tubing set: Y- type tubing with inflow and outflow segments

Dialysis cyclor: May be used for accurate delivery of volumes

Technique

Initial preparations: Bladder emptying, local anesthesia, initial infusion

Catheter insertion: Through the same puncture site to left pelvic gutter

Dialysis procedure: Cycles or runs of infusion and drainage.

Catheter removal: After a maximum period of 72 hours.

Monitoring

Clinical monitoring: Vital signs, ECG display, body weight.

Laboratory monitoring: Pulse oximetry, ABG, blood urea and electrolytes.

Complications

Complications of catheter insertion (traumatic injury, leakage, obstruction).

Complications of dialysis procedure:

Cardiopulmonary compromise.

Metabolic complications.

Peritonitis.

Acute peritoneal dialysis is a simple procedure that can be made in ICU or even in wards. It is more efficient in children, compared to adults, due to the relatively larger peritoneal surface area. In children, peritoneal dialysis is 50% as efficient as hemodialysis compared to only 20% efficiency in adults.

Peritoneal dialysis depends on the idea that the peritoneum is a semipermeable membrane across which water and solutes diffuse along their concentration gradients. Depending on this idea, excess body water (as in hypervolemia) and harmful metabolites (urea, potassium, sodium, hydrogen ion or poisons) can be removed from the body through the peritoneal route.

Peritoneal dialysis can be acute or chronic. In acute dialysis, the catheter has no cuff to seal its entry point and it can be used for a maximum period of 72 hours. In chronic dialysis, the catheter has a cuff to seal its entry point and it can be left in peritoneal cavity for 3 months.

INDICATIONS

Acute renal failure is by far the commonest indication of acute peritoneal dialysis and the procedure can be frequently life-saving. Indications of dialysis in acute renal failure can be either clinical or laboratory.

Indications of peritoneal dialysis in ARF

Clinical indications

- Anuria not responding to volume expansion, diuretics and dopamine infusion.
- Volume overload with congestive heart failure or pulmonary edema.
- Deteriorating neurological state in spite of the conservative measures.
- Gastrointestinal bleeding due to uremic platelet dysfunction.

Laboratory indications

- Blood urea above 150 mg/dl or rapidly rising level.
- Severe persistent metabolic acidosis (pH below 7.1) in spite of the conservative measures.
- Severe persistent hyperkalemia (above 7.0 mEq/litre).
- Hypernatremia (above 160 mEq/litre) with volume overload.
- Hyponatremia (below 120 mEq/litre) with volume overload
- Symptomatic hypocalcemia (tetany or convulsions) with hyperphosphatemia.

Nonrenal indications of acute peritoneal dialysis include severe hypernatremia (above 160 mEq/litre), severe organic acidemia with hyperammonemia, hyperuricemia and acute poisoning with toxins that are dialyzable.

Acute peritoneal dialysis is contraindicated in presence of infected abdominal wall, recent abdominal surgery, peritoneal adhesions or diaphragmatic defect. In these situations, hemodialysis is indicated as an alternative therapeutic measure.

DIALYSIS SOLUTIONS AND EQUIPMENT

Acute peritoneal dialysis is made with the following solutions and equipment:

1. **Dialysis solutions:** There are 3 available dialysis solutions. The standard 1.5% dextrose solution is the mainly used solution in most cases. Higher dextrose concentrations (2.5%, 4.25%) are initially indicated when a higher rate of fluid removal is required as in those with volume overload and pulmonary edema. In these situations, the hypertonic solution can be used for the initial few hours to be replaced after with the standard dialysis solution. The dialysis solutions should be warmed to 38°C before use. Heparin (250 IU/litre) should be added to the solution to prevent obstruction of the catheter by fibrin clots. Practically, 500 LU of heparin are added to each bag. As the dialysis solutions are free of potassium, hypokalemia may occur especially with rapid peritoneal dialysis. Therefore, potassium chloride should be added to the dialysis solution (2 ml of KC1 15% per litre = 4 mEq/litre) if hypokalemia occurs. Antibiotics as gentamicin may be added in an amount of 8 mg/litre (16 mg/bag).

Electrolyte concentration (mEq/litre) in the standard 1.5% dextrose solution

Na	Cl	HCO ₃	Ca	Mg
130	100	35	1.5	0.75

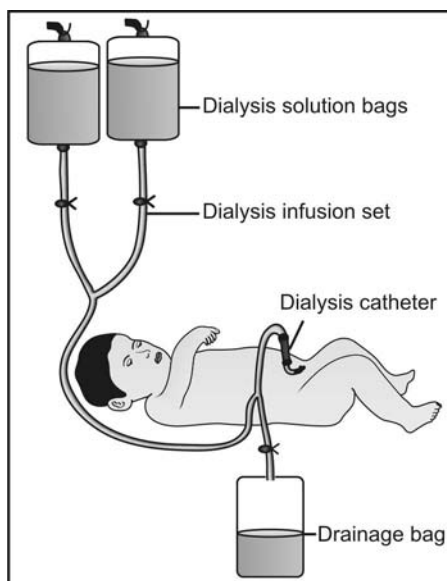
- 2. Dialysis catheters:** The acute dialysis catheters are somewhat rigid catheters. There are three available sizes (adult, child, infant) with the same internal diameter. In the adult size, the drainage holes extend for 8.4 cm from the tip of the catheter. In the pediatric size, the drainage holes are limited to the distal 4.2 cm, while in the infant size, the holes are only limited to the distal 2.5 cm. The choice of the catheter size is important because all the drainage holes should be inside the peritoneal cavity to avoid problems of leakage, infection and inaccurate recording of infusion and drainage volumes.
- 3. Dialysis infusion set:** It has a Y-type tubing at the distal end with inflow and outflow segments and another Y-tubing at the proximal end to be connected to two bags of dialysis solution. During infusion, the outflow segment should be closed to be only opened during drainage.
- 4. Dialysis cyler:** It can be used to allow accurate delivery of volumes. The standard cyler can deliver volumes in 100 ml increments between 100 ml and 3000 ml. A new pediatric cyler is available and can deliver a minimal volume of 50 ml with increments of 10 ml.

TECHNIQUE

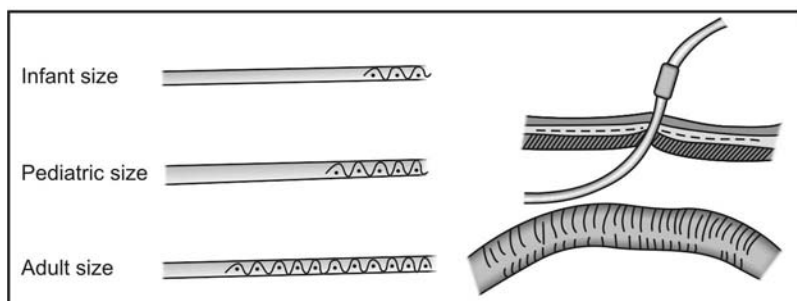
The process of dialysis can be divided into the following steps:

- 1. Initial preparations:** If the patient is conscious, initial sedation (diazepam, 0.1 mg/kg, I.V.) is useful to make the insertion of the catheter easier for the patient and the doctor. The bladder should be emptied of urine, spontaneously or by catheter if necessary. The abdomen is then scrubbed with antiseptic solution from the xiphoid to the groins and a sterile field is made between the umbilicus and the pubis. The chosen puncture site is infiltrated with 1% lidocaine and the infiltration should include the underlying muscle. The optimal puncture site is either (1) in the midline one third of the distance from the umbilicus to pubis, or (2) lateral to the rectus muscle in the left lower quadrant. With a standard 18-gauge intravenous catheter, the skin and muscles are punctured and the catheter is advanced just into the peritoneal cavity. 20 ml/kg of the standard dialysis solution are then infused into the peritoneal cavity. This initial infusion distends the abdomen and makes the subsequent catheter insertion easier. The intravenous catheter is then removed and more local anesthesia is infiltrated.

Peritoneal dialysis technique



Peritoneal dialysis catheters and catheter insertion



Summary of the initial preparation for peritoneal dialysis

Sedate the patient, if conscious, to make the procedure easier.
 Empty the bladder, spontaneously or by catheter.
 Sterilize the abdominal wall from xiphoid to groins.
 Infiltrate the chosen puncture site with 1% lidocaine.
 Puncture the skin and muscles with 18-gauge catheter.
 Advance the catheter just into the peritoneal cavity.
 Infuse 20 ml/kg of the standard dialysis solution.
 Remove the I.V. catheter and infiltrate the site with 1% lidocaine.

The optimal puncture site is in midline, one third of the distance from the umbilicus to the pubis.

2. **Catheter insertion:** While tenting the abdominal wall with one's fingers, the trochar and dialysis catheter are advanced into the peritoneal cavity through the same puncture site. The trochar and catheter should be held perpendicular to the abdominal wall and a twisting motion is used while advancing the catheter. Successful entry into the peritoneal cavity is evidenced by a sudden decrease in resistance and a rapid rush of peritoneal fluid up and around the catheter and trochar. Once the peritoneal cavity is reached, the trochar is removed and the catheter is advanced into the left gutter. The catheter is then cut to an appropriate length and is attached to the dialysis infusion set.
3. **Dialysis procedure:** It is made by repeated cycles or runs of infusion and draining out of the dialysis solution. Before infusion, the dialysis solution should be warmed to 38°C by using a warm water bath.
 - **Session length:** The dialysis procedure usually takes 24-72 hours. However, dialysis orders should be made for only 6 hours after which re-evaluation and new orders are given according to the response. The session is terminated when the clinical and laboratory parameters become normal and stable. A period of at least 24 hours is needed to achieve this objective.
 - **Exchange volume:** Initial cycles or runs (for 6-12 hours) are made with 20 ml/kg/cycle and the volume is then gradually increased to a final range of 40-50 ml/kg/cycle. The greater the volume used, the higher will be the clearance and the ultrafiltration rate.
 - **Cycle time:** The usual cycle time is 30-60 minutes and it is divided into inflow time (5-10 minutes), dwell time or peritoneal contact time (15-30 minutes) and outflow time (10-20 minutes). As inflow is made by gravity, inflow time depends on the infused volume. Dwell time may be shortened to achieve a more efficient rate of clearance and a more efficient dialysis. Outflow time should be longer than the inflow time to ensure complete emptying during drainage.
 - **Recording:** The cycle number, cycle time (inflow, dwell, outflow), inflow volume, outflow volume and cycle balance (difference between inflow and outflow volumes) should be recorded in a flow sheet. This should be combined with the clinical and laboratory evaluation.

Example of acute peritoneal dialysis prescription

Dialyze for 6 hours and re-evaluate.

Use the standard 1.5% dextrose solution and add heparin (250 IU/litre).

Exchange volume: 20 ml/kg/cycle.

Cycle time: 30 minutes.

Inflow time: 5 minutes

Dwell time: 15 minutes.

Outflow time: 10 minutes.

Record the cycle number, cycle time, inflow and outflow volumes and cycle balance.

Peritoneal dialysis flow sheet

[illegible]

4. **Catheter removal:** Once the dialysis procedure is terminated, the dialysis catheter should be removed. The maximum period of the acute catheter placement is only 72 hours because the incidence of peritonitis is much higher if the catheter remains for a longer period. Even if dialysis is still required after 72 hours, the catheter should be replaced by a new one and at a different puncture site.

MONITORING

Acute peritoneal dialysis is not without risks and close observation throughout the whole procedure is necessary. Cardiopulmonary compromise and disturbance of water and electrolyte balance are the most serious effects.

1. **Clinical monitoring:** Careful attention to cardiopulmonary status is necessary. Heart rate, respiratory rate and blood pressure should be recorded every hour. Continuous display of FCC is important for detection of signs of hyperkalemia. Temperature should be recorded every 6 hours and the patient should be weighed every 12 hours. Problems related to the catheter insertion (leakage) and dialysis procedure (abdominal pain) should also be observed.
2. **Laboratory monitoring:** Continuous or frequent monitoring of arterial oxygen saturation with pulse oximeter is useful for detection of any deterioration of respiratory function. Arterial blood gases (with the dialysis solution in and out) is useful to evaluate the effect of dialysis solution on pulmonary gas exchange. Blood urea, creatinine and serum electrolytes (Na, K, Ca, Cl) should be checked every 12 hours or more often if necessary until the values are stabilized. Blood sugar level should also be checked especially if a hypertonic dialysis solution is used. A specimen of the drained dialysis solution should be sent for culture daily or if peritonitis is suspected.

COMPLICATIONS

Complications of acute peritoneal dialysis can be related to the catheter insertion (traumatic injury, leakage, obstruction) or the dialysis procedure (cardiopulmonary compromise, metabolic complications and peritonitis). Abdominal pain during infusion is mostly due to the use of cold solution, use of hypertonic solution or too rapid infusion.

Complications related to catheter insertion

Traumatic injury of the bladder, intestinal loops or blood vessels may occasionally occur if the bladder is not emptied or the peritoneal cavity is not prefilled with dialysis solution before catheter insertion. Transient minor bleeding is a common problem, which is mostly insignificant. Leakage of dialysis solution may occur if part of the perforated tip of the catheter is preperitoneal, if the catheter is not properly sutured or if the abdomen is overdistended. Obstruction of the catheter may occur by fibrin or omentum.

Complications related to dialysis procedure

1. **Cardiopulmonary compromise:** Impairment of pulmonary and cardiovascular functions are serious complications that should be early detected and promptly corrected.
 - a. **Pulmonary compromise:** The infusion of a large volume of dialysis solution into the peritoneal cavity increases the intra-abdominal pressure and causes elevation of the diaphragm and restriction of the diaphragmatic mobility. This may result in defective oxygenation, alveolar hypoventilation and increased work of breathing. Reduction of the exchange volume (only 20-30 ml/kg/cycle) and shortening of the peritoneal contact time or dwell time (only 5-10 minutes) are usually sufficient to control the problem. Positive pressure support may be needed in extreme conditions.
 - b. **Cardiovascular compromise:** Hypotension is a serious complication, which may occur due to hypovolemia and/or impairment of venous return. Hypovolemia may occur due to rapid removal of a large volume of body fluids especially when a high concentration of dialysis solution (4.25 % dextrose) is used. Impairment of venous return and reduction of cardiac output may occur due to increased intra-abdominal pressure especially when a large exchange volume is used. Treatment of hypotension is made by volume expansion (20 ml/kg of Ringer's lactate, I.V. over 10 minutes), use of standard dialysis solution (1.5% dextrose) and reduction of exchange volume (only 20-30 ml/kg/cycle).
2. **Metabolic complications:** Dehydration may result from the excessive removal of body fluids especially when a hyperosmotic solution (4.25% dextrose) is used. Hyperglycemia is another complication of hyperosmotic solutions. Hypokalemia may occur due to continued use of potassium-free dialysis solution after potassium has returned to normal. Therefore, potassium should be added to dialysis solution (in an amount of 4 mEq/liter) when serum potassium returns to normal level. Metabolic alkalosis may occur due to impaired renal mechanism for bicarbonate excretion.
3. **Peritonitis:** It is a serious complication, which occurs in 30-50% of cases. Measures to reduce the incidence of peritonitis include (1) use of strict aseptic technique, (2) sterile dressings over the catheter, (3) use of closed dialysis delivery system, (4) avoidance of prophylactic antibiotics that may predispose to candida infection, (5) early removal of the catheter after 48 hours. Early detection of peritonitis by daily culture of the drained dialysis solution is important. Treatment should be guided by the results of culture-sensitivity studies.

Doctor’s treatment sheet

DRUG THERAPY

No.	Generic name	Trade name	Dose / kg	Practical dosage	Route	Day
1						
2						
3						
4						
5						
6						
7						
8						
9						

I.V. fluid therapy

No.	Solution	Amount	Start time	D/C time	Rate
1					
2					
3					
4					
5					

Transfusion

Nutrition

Respiratory support

O ₂	Aerosol	CPT	Suction	ETT	M. Ventilation
				<div>Size</div>	<div>CPAP</div>
				<div>Route</div>	<div>IMV</div>
				<div>Length</div>	<div>CMV</div>

OTHERS

Dialysis

Phototherapy

Radiant warmer

SURGERY



Section 12

Pediatric ICU Equipments

- Airway Equipment
- Oxygenation Equipment
- Ventilation Equipment
- Circulation Equipment
- Monitoring Equipment
- Diagnostic Equipment

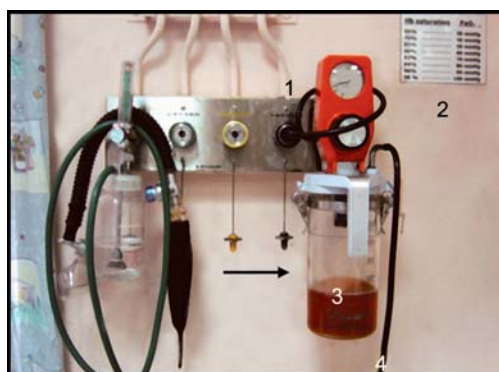
55 Chapter

Airway Equipment

Suction canister setup

It consists of the following:

1. Vacuum outlet.
2. Manometer to measure the suction pressure.
3. Collecting bottle for drainage of secretions.
4. Connecting tubing to reach from the setup to the suction catheter.



Oropharyngeal suctioning

Suctioning is very important in clearing the airways and in improving ventilation. Suctioning is a stressful procedure which may precipitate cardiopulmonary arrest. Preoxygenation with the bag and mask (with 100% oxygen) is important to avoid hypoxia that may occur during suctioning.



Endotracheal suctioning

Suctioning is only made for 5 seconds per time.

The suitable suction pressure is 60-90 mm Hg in infants and 90-120 mm Hg in children.

Suctioning should also be followed by hyperoxygenation.



Oropharyngeal airway

It is used in comatose patients and during cardiopulmonary resuscitation to keep the airway open and to prevent backward displacement of the tongue.



Ultrasonic nebulizer

It is used to liquefy viscid secretions to allow easy suctioning. It is also used to provide inhaled drugs as salbutamol in patients with severe asthmatic attacks.



Laryngoscope and Endotracheal tube

They are used to insert an endotracheal tube prior to mechanical ventilation. There are different sizes for different ages.

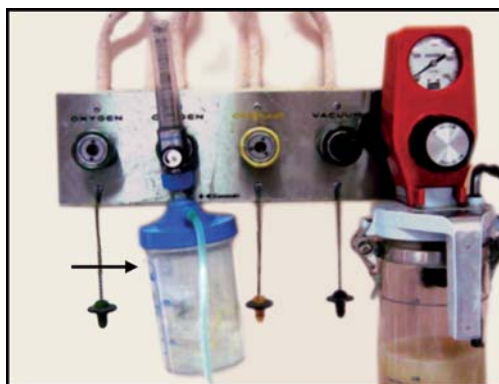


56 *Chapter*

Oxygenation Equipment

Oxygen flowmeter and humidifier

It is the part that controls the flow of oxygen (in litres per minute) and it also humidifies the dry oxygen.



Simple oxygen mask

It is the most simple way to give oxygen. However, the oxygen concentration cannot be measured. There are different sizes for different ages.



Venturi oxygen mask

It is used to deliver precise oxygen concentration by using different colored valves (24%, 30%, 40%, 50% and 60%). It is much better than simple masks.



Nasal prongs

It is used to deliver oxygen at a low flow rate. It may be more tolerated by some patients better than masks. The oxygen concentration cannot be measured.



Head box

It is the most suitable way to give oxygen for infants. The oxygen concentration can be measured by the oxygen analyzer. A high concentration up to 100% can be given. Note also the "pulse oximeter", which measures the arterial oxygen saturation.



Oxygen analyzer

It is used to measure the oxygen concentration (%) inside the head box or inside the incubator. In this patient, oxygen concentration is 72%.



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Chapter

Ventilation Equipment

MANUAL VENTILATION

Bag and mask (Ambu bag)

It is used in manual ventilation during cardiopulmonary resuscitation. It can be connected to oxygen to give 100% O₂.



Bag and mask (Anesthesia Bag or Jackson Rees bag)

It can be used in ICU instead of Ambu bag. It is always connected to oxygen.



Bag and tube ventilation

It is used in intubated patients to induce hyperoxygenation before and after endotracheal suctioning.



MECHANICAL VENTILATION (THE VENTILATORY SYSTEM)

The ventilatory system has five main components:

1. **Oxygen and compressed air:** The oxygen blender of the ventilator mixes the oxygen and compressed air to deliver the desired oxygen concentration.
2. **Electricity connection.**
3. **Ventilator:** It has several knobs to control the different parameters of positive pressure support (see opposite page).
4. **Humidifier:** It humidifies the blended mixture of oxygen and compressed air before being delivered to the patient. All humidifiers of ventilators are also capable of heating to deliver heated humidified mixture.
5. **Patient breathing circuit:** This tubing system has two limbs; inspiratory and expiratory. The inspiratory limb (A) extends from the ventilator to the humidifier then from the humidifier to the endotracheal tube connector of the patient. The expiratory limb extends from the endotracheal tube connector back to the ventilator.



VENTILATORY SETTINGS

Each ventilator has different knobs and displays for control of different parameters:

1. Mode of support: CPAP or IMV.
2. Set FIO_2 : The desired oxygen concentration (ranging from 21% to 100%).
3. Flow: The volume delivered in litres per minute.
4. Inspiratory time: The time of mandated breath in seconds.
5. Set rate: The number of mandated breaths per minute.
6. CPAP or PEEP control: To control the required pressure in cm water.
7. PIP control: It controls the maximum pressure limit during inspiration.
8. Tidal volume: It displays the delivered tidal volume per minute.
9. I/E ratio: It displays the inspiratory/expiratory ratio.
10. Total rate: It displays the total respiratory rate of the patient.
11. PEEP level: It displays the selected PEEP.
12. Spontaneous flow.
13. Low pressure.
14. High pressure.
15. Pressure display: It displays the highest (peak) and lowest pressure (PEEP).



58 Chapter

Circulation Equipment

I.V. set infusion pump

It is used to deliver I.V. fluids at a precise rate. The patient may use several pumps at the same time.



Syringe infusion pump

It is used to deliver serious drugs at a constant rate by continuous I.V. infusion. The mainly used drugs are dopamine and dobutamine in severe shock states.



Defibrillator

It is used in patients with ventricular fibrillation to return the heart to normal sinus rhythm. This form of arrhythmia is uncommon in children.

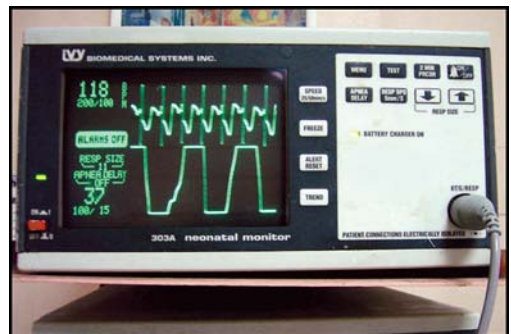


59 Chapter

Monitoring Equipment

Monitor for HR and RR

All patients in ICU are physiologically unstable and cardiopulmonary arrest may occur unexpectedly. Therefore, continuous monitoring of heart rate and respiratory rate are essential. Sound alarm should be set to ring if heart rate or respiratory rate comes below certain values.



The three electrodes of the monitor attached to skin of chest and abdomen



Blood pressure measurement (DINAMAP)

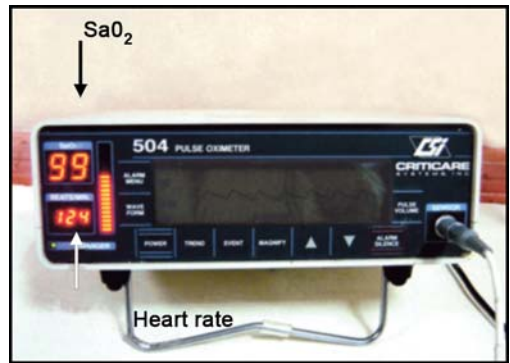
Measurement of blood pressure is important for detection of shock and hypertension.

DINAMAP is used for repeated or continuous monitoring of blood pressure. It measures the systolic, diastolic and mean arterial pressure. DINAMAP means "Device for indirect noninvasive automated mean arterial pressure".



Pulse oximeter

Continuous monitoring of arterial O_2 saturation (SaO_2) with pulse oximeter is a simple noninvasive way for assessment of oxygenation. Pulse oximeter measures arterial oxygen saturation (arrow) as well as the heart rate. Normal value is above 95%. Value below 95% necessitates oxygen therapy and value below 90% requires mechanical ventilation.

**End-tidal CO_2 monitor**

Continuous monitoring of the end-tidal CO_2 in mechanically ventilated patients is useful to assess the adequacy of ventilatory support and to minimize repeated measurements of blood gases. Value above 45 mm Hg indicates that the patient is undersupported.



Pulse oximeter (1) and End-tidal CO_2 monitor (2) used in a mechanically ventilated infant



60 Chapter

Diagnostic Equipment

PICU Laboratory

Intensive care laboratory should perform the following tests:

1. Blood gases.
2. Serum electrolytes (Na and K).
3. Complete Blood Count (CBC).
4. Blood chemistry: Blood urea and creatinine, blood sugar, serum bilirubin and serum calcium level.



Na and K



Blood gas analyzer



Blood count



Blood Chemistry



Section 13

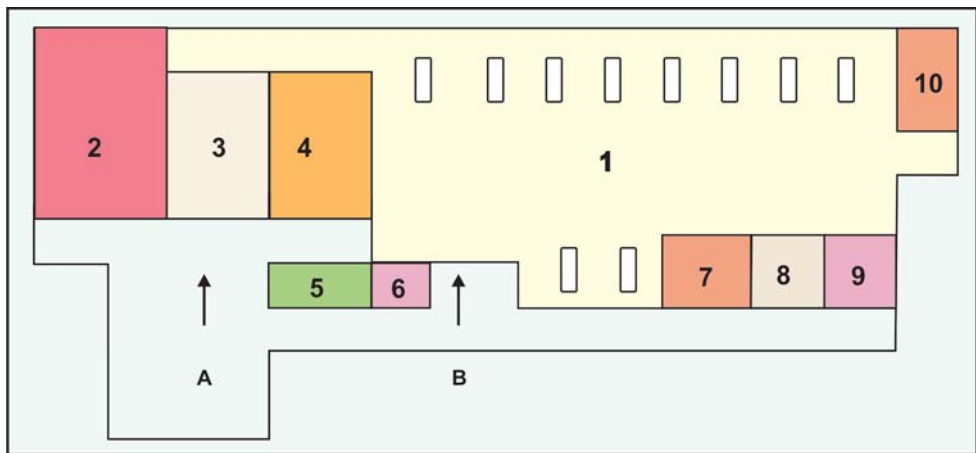
Pediatric ICU Environment

- Pediatric Intensive Care Unit Design
- Bed Settings
- Infection Control
- Teamwork and Recording

61 Chapter

Pediatric Intensive Care Unit Design

PICU design of Cairo University Pediatric Hospital



Pediatric intensive care unit (PICU) is not just a big ward with beds and equipment. It is a unit with different areas that act together to provide the optimal care for sick children. Ideally, intensive care unit should contain 10 areas:

1. Main intensive care area: It contains the beds and the necessary equipment.
 2. Professors and meeting room.
 3. Doctors room.
 4. Nurses room.
 5. ICU lab.
 6. Workers room.
 7. Storage (stock) room.
 8. Sterilization room.
 9. Head nurses room.
 10. Data base room.
- A: Entry of staff.
B: Entry of Patients.



PICU main area

PICU main area should not be crowded. Sufficient space should be available between each 2 beds to allow for placement of equipment and free movement of personnel at both sides of each bed.

The unit should be centrally air-conditioned and lighting inside should be sufficient to allow good observation.



Sterilization room

In this room, washing and ironing of bed sheets and gowns are made. Sterilization of dresses and surgical equipment by autoclaving is also done (see sterilization).



Storage (Stock) room

It is used for storage of:

1. I.V. fluids.
2. Several ICU disposables (as suction catheters, feeding tubes and endotracheal tubes)
3. ICU equipment (as portable X-ray machine, ventilators and nebulizers).
4. Admission and flow sheets.



Database room

Keeping patients records and analysis of results are very important. Each unit should have its own computer database.



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Chapter

Bed Settings



Each bed in IUC should be equipped with the following:

1. Central medical gases: Oxygen, compressed air and vacuum (suctioning).
2. Electricity plugs.
3. Monitor for heart rate, respiratory rate and ECG display.
4. Mechanical ventilator.
5. Pulse oximeter for measurement of arterial oxygen saturation.
6. Infusion pump for I.V. fluids.
7. Radiant warmer to keep body temperature and to prevent hypothermia.
8. DINAMAP for blood pressure measurement.
9. Table for files, flow sheets and recording.
10. Dustpan under the bed for wastes.



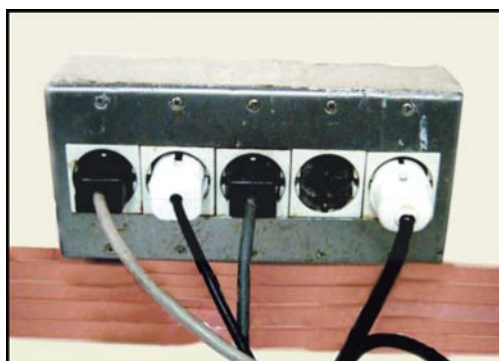
Medical gases

Medical gases should contain two oxygen outlets (1 and 2), one compressed air for ventilators (3) and 2 suction outlets (4 and 5). The two oxygen outlets are important (one for oxygen therapy and the other for hyperoxygenation before stressful procedures as suctioning).



Electricity plugs

At least, 5 electricity plugs should be available (for monitor, pulse oximeter, ventilator, infusion pump and radiant warmer). Ideally, other 5 plugs should be available as many patients use more than one pump and other equipment as monitors for blood pressure and end-tidal CO₂ may also be used.



Radiant warmer

All patients in PICU are subjected to hypothermia because of their critical illness and the air-conditioned environment. Keeping the body temperature by radiant warmers is necessary especially in infants and young children.



63 Chapter

Infection Control

Measures for Infection Control



Measures to control infections inside ICU should be known to all staff working in the unit (doctors, nurses technicians and workers).

In our unit, these measures are fixed on the wall beside the sink (arrow) to be seen and read by all staff while washing their hands.

It is important to know that the incidence of infections is directly proportionate to the number of personnel inside the unit. It is significantly higher in large units and units in teaching hospitals where students and trainees are present. Therefore, unnecessary personnel should not be allowed to enter.

Measures for Infection Control

1. Gowns and overshoes should be used by all personnel.
2. Strict hand washing for at least one minute using soap, water and brush.
3. Use of hand antiseptic before examination of every patient.
4. Strict aseptic techniques for catheter insertion, suctioning and endotracheal intubation.
5. Water in oxygen humidifiers and ventilator humidifiers should be changed daily.
6. I.V. lines should be changed every 3-5 days.
7. Endotracheal tubes should be changed every 5-7 days.
8. Visitors are only allowed during the visiting hours.

Hand washing for one minute with soap, water and brush

Hand washing is the most important single factor in controlling infections inside ICU. Unfortunately, many doctors are reluctant to follow this simple rule. Ideally, one person should be assigned to observe all personnel while washing their hands.

**Antiseptic solution before examination of any patient**

Cross infection can occur through hands of doctors and nurses. Use of antiseptic solution before examination of every patient minimizes this risk.

**Strict aseptic techniques**

Catheter insertion, suctioning and endotracheal intubation should be all done using aseptic techniques. Sterile gloves should be used and suction catheters should be sterile.



Sterilization of the unit



Regular full sterilization of the unit should be made periodically every 2-3 months.

It includes the following:

1. The main area (walls, floors, counters, tables and beds)
2. Medical equipment.



Sterilization System in our PICU

1. **Washing and cleaning:** All beds and equipment inside the unit are washed thoroughly with hot water and soap to remove any attached materials. This is followed by rinsing with running water.
2. **Sterilization:** The used disinfectants (that kill microorganisms on nonliving surfaces) are:
 - Sodium dichloro-isocyanurate anhydrous: It is a chlorine releasing compound used for sterilization of beds, tables, counters and some medical equipment as suctioning and oxygenation equipment.

The used concentration depends on the purpose:

 - Medical equipment: 2 tablets /1.2 litres water.
 - Beds, tables and counters: 1 tablet /1.5 litres water.
 - Feeding bottles: 1 tablet /12 litres water.
 - Ethylene oxide gas (EO): In the central sterilization unit of the hospital, ethylene oxide gas is used for sterilization of plastic tubing of ventilators, oxygen therapy and nebulizers.
 - Potassium monopersulphate (Virkon): This anionic surfactant material is sprayed in the unit to sterilize the walls, floors, ceilings and air conditioning outlets. Then, the unit is closed for 48 hours.
 - Autoclaving is used to sterilize dressings and surgical equipment.
3. **Washing and cleaning:** The unit is reopened and all beds, floors, walls and medical equipment are washed again.
4. **Evaluation of sterilization:** Swabs for cultures-sensitivity studies are taken from different areas (beds, counters, different medical equipment). Negative cultures from these areas indicates successful sterilization process.

Antiseptic: Substance that kill microorganisms on living surface (as skin).

Disinfectant: Substance that kill microorganisms on nonliving surfaces.

64 *Chapter*

Teamwork and Recording

United We Stand ... Divided We Fall.



Pediatric intensive care unit is an area of "multiple care givers". The care and outcome of any patient depend mainly on cooperation between all staff in the unit.

Good and warm relations between all members are highly important to achieve these objectives. Regular meetings for evaluation, discussions and even social events are important. Proper recording is very important to allow good communication between different personnel rotating throughout the 24 hours. Responsibilities inside the unit should be assigned carefully and precisely.

Published Books

- Pediatric Clinical Diagnosis
- Practical Pediatric Therapy
- Basic Clinical Pediatrics
- Basic Pediatric Radiology
- Pediatric Critical Care
- CT Scan in Pediatrics
- Pediatric Emergency Medicine
- Short Atlas in Pediatrics

Next Coming Books

- Common Mistakes in Pediatric Practice

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